ИЗВЕСТИЯ
АКАДЕМИИ НАУК СССР
СЕРИЯ ГЕОЛОГИЧЕСКАЯ

IZVESTIYA AKAD. NAUK SSSR

SERIYA GEOLOGICHESKAYA

| 1959 | CONTENTS | No. 9, September |
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BRIEF COMMUNICATIONS

REVIEWS AND DISCUSSIONS



CHRONICLE





T-08956. Approved for printing August 21, 1959
Circulation 3,850 copies. Order 3611
Paper size 70 x 108-1/16. Paper 10.27 + 2 ins. Publ. sheets 12.4 Paper 3-3/4

Second printing office of the USSR Academy of Sciences Publishing House
Moscow, Shubinskiy per. 10

# THE DETERMINATION OF REGULAR PATTERNS
# N THE DISTRIBUTION OF MINERAL DEPOSITS THROUGH THE U.S.S.R. — THE MOST IMPORTANT BRANCH OF GEOLOGIC STUDY[1]

by

V. I. Smirnov

The reorientation of Soviet science in the ight of major State economy tasks set up by he Twenty-First Congress of the CPSU (Com- nunist Party of the Soviet Union) has sounded n urgent call for Soviet geologists to concen- rate their best efforts in working out the roblem of geologic regularity in the distri- ution of mineral deposits throughout the oviet Union.

This problem was designated a leading one, ome five years ago, by Academician N.S. hatskiy and has been supported by a large umber of Soviet geologists. The general neeting of the U.S.S.R. Academy of Sciences, his current year, recognized it as the most mportant field of geologic study.

There is no doubt that mineral deposits re distributed according to definite laws letermined by the geologic history of a given egment of the earth's crust and are related o this history by the evolution of the physical nd chemical features of their mineralization nedia. However, the regular relationship etween the localization of mineralization and arious aspects of geologic processes is so omplex that even a well organized study of t by most advanced methods does not always eveal it definitely and unequivocally. For his reason, the unravelling of natural patterns n the distribution of mineral ore deposits is n important problem requiring the combined ffort of geologists.

The determination of such regular patterns or all raw mineral material of different genetic types formed at different epochs would resent a scientific basis for well directed geologic prospecting and insures its efficiency. The unravelling of these patterns is important n the forecasting of new mineral sources also ecause the number of relatively easy-to-find re deposits is getting smaller, and a new problem looms before us — that of discovering new mineral accumulations in complex geo- logic conditions of concentration at depth, without guiding outcrops, and often controlled by complex structural and facies factors.

A solution of this problem is complicated by the necessity of discovering mineral depos- its of high quality, primarily in accessible areas, and occurring under conditions favor- able for development by advanced methods. Especial importance is attached to the search for high quality mineral deposits.

In some branches of the mining industry, such as metallurgy of non-ferrous metals, much lower grades of ore are worked in this country, as compared with capitalist countries. Now, for instance, a rise of only 0.5 to 0.7% in lead content in an industrial ore will raise the productivity in the lead industry by 15 to 20%. Therefore, securing new mineral resources of higher grade is important in the struggle to raise our per-capita productivity, emphasized on many occasions by the Party instructions and by the resolutions of the Twenty-First Congress of the CPSU. This is the worthy contribution of Soviet geologists to the effort of our people in its peaceful eco- nomic rivalry with the most advanced countries of the capitalist camp.

The discovery of the relationship between various ore deposits and the elements of geology which determine their patterns of spatial distribution is important not only for practical purposes but also for the develop- ment of genetic theory. An analysis of regional features of the distribution of ore deposits, coupled with a structural and facies differenti- ation of a region under study, discloses many essential features of the origin of such deposits.

Soviet geologists have long been interested in geologic regularities in spatial distribution of mineral deposits. This interest is stimu- lated by the especially favorable conditions for a regional study of mineral potential over the immense expanse of our country, with formations and tectonic structures of all

[1] Vyyavleniye zakonomernostey razmeshcheniya oleznykh iskopayemykh v nedrakh territorii SSSR — azhneysheye napravleniye geologicheskikh issledo- vaniy.

geologic cycles — from the Archaean to the Alpine — developed in it, with their diversified and often unique deposits of all kinds of minerals of the most divergent genetic types.

V.A. Obruchev, a versatile student, was often attracted to this fascinating problem. His early works in this field were carried out in the twenties of this century and deal with the nature of metallogenic epochs and provinces of Siberia. He recognized the Archaean, the Eozoic, the Caledonian, the Hercynian, the Tyan'-Shan', and the Mesozoic metallogenic epochs in Siberia, with endo- and exogenic ore deposits of their own, and with the corresponding metallogenic provinces and areas. Later on, in the thirties, V.A. Obruchev set forth geologic premises for the distribution of the most important minerals separately for shields, platforms, and geosynclines. In the forties, he worked on the problem of geological regularities and forecasting (see Sovetskaya Nauka, no. 5, 1940).

It should be noted that just at that time the Soviet Government called the attention of the U.S.S.R. Academy of Sciences to the necessity for development of geologic forecasting, and the Academy responded by including the project of compiling exploration maps in its 1940 work schedule.

A.Ye. Fersman, with his brilliant geochemical ideas, stubbornly pushed forward into the realm of natural laws governing the distribution of minerals, as manifested in the distribution of ores of various composition throughout the vast expanse of the Soviet Union. The regional metallogenic zonation of the Mongol-Okhotsk belt, noted and vividly described by him, was used as a basis for regional studies of the ore potential in Eastern Siberia, by S.S. Smirnov, the father of Soviet metallogeny. The scientific glory of S.S. Smirnov is due to a considerable extent to his talented analysis of regularities in the distribution of ore deposits in the Eastern Trans-Baykal Region, the Verkhoyan'ya Region, and the Pacific metallogenic belt as a whole. In his development of S.S. Smirnov's ideas, Yu.A. Bilibin has presented his well-known and well-substantiated general concept of regularities in the formation and distribution of endogenic mineral deposits in mobile zones of the crust, in the process of change from geosynclinal systems to folded belts.

The geologic regularities of the lateral distribution of coal are presented in works of P.I. Stepanov. He described the epochs during which coal accumulated and designated the world's belts and centers of coal accumulation. Regularities in the distribution of oil fields were outlined by I.M. Gubkin. He described the distribution of oil according to geologic systems and oil provinces, and formulated the basic law of the occurrence of oil fields in peripheral zones of mountain systems and in the direction of the plunge of mountain systems.

Recent years have witnessed an especially intensive study of regular patterns in the distribution of mineral deposits in the crust. According to data of the Council of Study of Regular Patterns in the Distribution of Principal Minerals, Section of Geologic and Geographic Sciences, Academy of Sciences of the U.S.S.R., this subject is dealt with in 620 papers published by various scientific research organizations of this country.

The vast, truly inexhaustible material on geology of assorted minerals, accumulated in connection with the gigantic enterprise of geologic exploration and mining work in this country since the advent of Soviet power, has called for special methods of scientific analysis, capable of mass assimilation of this material. One of the most accessible and effective methods of synthesis of the diversified data on the geology of minerals involves the use of composite maps of their actual and possible distribution, often compiled on a purely geologic basis. Such maps, revealing the geologic conditions of formation of minerals is a contribution to science, on one hand, and a reliable basis for rational direction of prospecting, on the other.

The knowledge of regular patterns in the distribution of various groups of minerals in a specific geologic environment promotes a comprehensive development of the theoretical basis of geology, revealing the causal relationship of such regular patterns and the geologic history and structure of a given segment of the crust of the earth. Of course, different branches of geology are called into play in connection with different groups of minerals and with different genetic conditions. Consequently, it may be stated that all branches of geologic science are involved in the discovery of regular patterns in the distribution of mineral deposits. Accordingly, the final solution of this problem is impossible without a joint effort of geologists specializing in all branches of their science.

Stratigraphers can be of substantial assistance in the solution of this problem, with their continuous improvement of ideas on general and especially local periods of formation of exogenic mineral deposits. Without such works as the familiar study of N.M. Strakhov on the period of accumulation of sedimentary ores of iron, manganese, and aluminum, or of P.I. Stepanov's hypothesis of coal accumulation, it would be impossible to develop the study of regular patterns in the distribution of minerals.

Paleogeographic and paleoclimatic analysis,

not sufficiently used as yet in the study of these regular patterns, is destined to play a large part in determining the features of formation and distribution of coal deposits, the weathered crust, and in part the conditions of oil and gas accumulation.

It is to be hoped that extensive and original investigations of sedimentary formations and their mineral productive capacity, as developed under the direction of N.S. Shatskiy, despite the criticism of some geologists, will lead to a better understanding of the distribution of various exogenic mineral deposits. The comparative lithology (facies) method of N.M. Strakhov, competing to a certain extent with that of N.S. Shatskiy, also merits recognition. Generally speaking, no single method should be given preference in such an actively developing branch of knowledge as the study of regular patterns in the distribution of mineral deposits. There is room enough for application of different methods and there is a chance to evaluate their efficiency by their results — the finding of new sources of mineral raw material.

Geomorphic analysis, logically and profitably applied in the works of Yu.A. Bilibin, I.S. Rozhkov, and others, maintains its importance in determining the distribution of such groups of deposits as placers and the weathered crust.

The role of geochemistry in the study of spatial regularities in the distribution of minerals is unfortunately small, as yet, although the unravelling of the regional occurrence of individual elements and their paragenetic associations might lead to a better understanding of some features of regional distribution of both the exo- and endogenic mineral deposits.

Geophysical methods, too, are used only to a small extent for this purpose, especially in the study of deeper geologic structures which control the regional zones of mineral accumulation. The introduction of geophysical and other precise methods utilizing modern achievements of technology, physics, and mechanics might shed new light on the problem of regular distribution of mineral substances through a study of the features of various rock complexes and the processes taking place in them.

Domestic and foreign study has done much to clarify the relationship between the formation and distribution of extrusive rocks and of endogenic mineral deposits, as witness the works of A.N. Zavaritskiy, S.S. Smirnov, Yu.A. Bilibin, Kh.M. Abdullayev, and others. This field of study promises to retain its importance in the determination of regular patterns in the distribution of igneous mineral deposits. Consequently, this problem cannot be successfully attacked without further progress in petrology.

Tectonics is most important in determining the distribution of nearly all minerals, and is likely to maintain its leading position in the future. A study of tectonic conditions of the formation, displacement, and distribution of mineral deposits nearly always is a key to the determination of regional distribution of metal, coal, and gas. Descriptive tectonics which deals with the present tectonic structures is not so important in this respect, but historical tectonics — if such a term may be used — which reveals the evolution of tectonic forms from their inception to the present state. Only the historic aspect of tectonic and structural facies analysis, in both its broad sense as embracing individual geosynclines and platforms, and in a more narrow framework of individual areas of development of minerals, affords the means of detecting the laws of origin and distribution of mineral raw material in the interior of the crust. This is why practical geologists whose business it is to determine and predict the distribution of minerals, are very much interested in the achievements in this branch and closely follow its development.

The development of theoretical premises for regular patterns in the distribution of minerals is coupled with compiling maps which show the known and anticipated distribution of various mineral groups. A synthesis of all geologic data which control this distribution on maps is the basic method of solution for the problem in question. Certain problems of detail arise, such as the method of making the maps, the selection of an appropriate geologic base map and the criteria for any given mineral, as well as the map scale.

The preparation of a geologic base map for the known and anticipated distribution of minerals (exploration maps) is facilitated by the progress in geologic mapping of the Soviet Union. However, the technique of working out such bases is fairly complex and controversial. As shown by the experience of the Kazakhstan Academy of Sciences' geologists working under the direction of K.I. Satpayev, even simple plotting on a geologic map of points of ore deposits, broken up into age groups and formations, is a great help in the understanding of the conditions of occurrence for industrial accumulations of ferrous, non-ferrous, and rare metals. However, for a better representation of regular patterns in the distribution of minerals, a geologic base map should be modified to represent first those geologic factors which control these regularities. An example of such maps are the oil exploration maps of Eastern Cis-Caucasus compiled by I.O. Brod and his coworkers. These maps

show the rocks according to their reservoir properties, and the geologic structures according to their capacity for oil accumulation.

The methods of compilation of a geologic base for mineral exploration maps is being developed by many of our scientific research and industrial organizations. Some workable suggestions are undoubtedly forthcoming as a result of their activity. For instance, those geologists who study the regular patterns in the distribution of minerals in sedimentary rocks believe in the importance of lithologic facies maps for the entire Soviet Union and its major provinces.

Experience has demonstrated that the exploration maps are adequate when, in addition to known deposits, they present all showings and evidence of minerals. Such maps, as source material for the mineral distribution maps, will be of the same importance in geologic mapping as the maps with actual data.

The mineral distribution maps may be simple or complex. The latter show all or some of the mineral groups known from a given area; the simple maps show only the distribution of a single mineral group. The complex maps are useful for demonstrating the regional relations between deposits of different minerals but inconvenient for forecasting the distribution of individual types of mineral raw material. The most useful among them are those showing the distribution of minerals paragenetically related to each other (such as oil and gas; molybdenum, tungsten, and tin; and — for certain regions — arsenopyrite and gold; etc.). The simple maps have a wider use, especially in a large-scale determination of distribution of minerals. The technique of plotting the locations of minerals on such maps is not simple, because a single symbol must include a number of indexes, such as age, size, the mineral and chemical composition, genetic type, etc.

Any map of mineral distribution is of scientific and practical value only when it shows not only the known ore deposits but also the outlines of areas of known and anticipated productivity, as determined by the zones of distribution of geologic factors controlling the presence of such deposits.

The scale of such maps may be different for different purposes. The Joint Scientific Session on Metallogenic and Exploration Maps, held at Alma-Alta at the end of 1958, designated three scales for the ore deposit distribution (metallogenic) maps: 1 -- small scale, 1:1,000,000 and smaller for index maps embracing all or most of the Soviet Union; 2 -- intermediate scales, 1:1,000,000 to 1:200,000, for exploration metallogenic maps of large ore provinces, such as the Far Northeast, Maritime Province (Primor'ye), Eastern Trans-Baykal Region, Siberian Platform, mountain fringe of Central Siberia, Urals, Kazakhstan, Central Asia, Caucasus, Ukraine, and Northwest U.S.S.R.; 3 -- large scale, 1:200,000 and larger, for the exploration map of individual ore regions. Obviously, this grouping is applicable for the distribution maps of many non-ore minerals, such as coal, oil, and combustible gas.

It appears reasonable that such maps for the entire Soviet Union and for its major subdivisions should be compiled by the central scientific research academic and local institutes, drawing upon resources of the Ministry of Mineral Resources and Geology, on the provincial geologic libraries, and on the results of study by other central and local geologic organizations.

The intermediate-scale maps of known and anticipated distribution of minerals, for individual provinces, basins, and regions should be compiled by local scientific research and production geologic centers, enlisting the assistance of individual groups of scientists from central institutions.

Finally, the large-scale regional maps of mineral distribution should be compiled by local production geologic organizations with the participation of qualified experts from scientific research institutes, especially as far as the technique of gathering data and compilation of maps are concerned. Many maps on such scales make possible a qualitative estimate of the anticipated new reserves, as a result of new discoveries.

The compilation of mineral distribution maps on different scales will call not only for a systematization of domestic data but for taking advantage of world data, as well. With this in mind, it is quite reasonable to anticipate the compilation of maps showing distribution of groups of ore deposits for individual continents and for the entire earth. Such a project, carried out by the international geologic associations, would undoubtedly promote advanced study of regular patterns in the distribution of minerals in the crust.

We already have some experience in making maps for actual and anticipated distribution of various minerals. Maps of coal and oil bearing areas of the U.S.S.R. were prepared some time ago, along with those showing distribution of gold. Metallogenic maps for iron are now in the process of preparation. A series of metallogenic, coal, and oil maps have been compiled for some areas of the U.S.S.R., together with those for some non-metals (phosphates, salt, etc.). However, up to now this work has been done in a fragmentary way,

without a unifying plan and without a common method; in the future, such work should be systematized and planned.

As a specific project for the current seven years, the Soviet geologic fraternity could undertake the making of small-scale index maps and of intermediate-scale maps showing the distribution of most important minerals. At the same time, this period should witness the completion of index maps of the Soviet Union for ore deposits, oil, and gas.

The creative group of the metallogenic group of the VSEGEI (All-Union Geological Scientific Research Institute), which has accomplished much in the field of metallogeny in this country, should complete the 1:2,500,000 metallogenic map of the U.S.S.R.

The Coal Geology Laboratory, Academy of Sciences, U.S.S.R., will complete the map of coal provinces of the U.S.S.R. and the coal accumulation maps for the Carboniferous, Permian, lower Mesozoic, upper Mesozoic, and Tertiary (at a scale of 1:5,000,000).

The Institute of Geology and Exploitation of Fossil Fuels, Academy of Sciences, U.S.S.R., has assumed the leadership in making a 1:2,500,000 oil and gas map of the U.S.S.R.

It would be desirable to compile, in the same period, index maps reflecting regular geologic patterns of distribution in this country of deposits of salts, natural agricultural fertilizers, iron, aluminum, copper, lead and zinc, rare and dispersed elements, and other types of mineral raw materials.

The seven year plan includes the completion of intermediate-scale maps of the known and anticipated distribution of mineral deposits. A 1:1,000,000 to 1:200,000 metallogenic exploration map is proposed for all ore provinces of the Soviet Union; coal distribution maps by basins and regions, on the same scale; and oil maps for the corresponding provinces of the country. Simultaneously with the making of large- and intermediate-scale maps of the Soviet Union as a whole and of its major ore provinces, coal basins, and oil regions, more detailed mapping will be carried on in order to determine the distribution of minerals in the most important areas where they are concentrated.

Up to now, the analysis of the distribution of regular patterns embraced only those minerals which were deemed the most important, such as oil, coal, iron, manganese, titanium, boron, aluminum, copper, zinc, lead, tin, molybdenum, mercury, nickel, cobalt, rare and dispersed elements, phosphorus, and potassium and rock salts. It appears that in the future, too, at least in the immediate future, efforts should be concentrated on the distribution of regular patterns for only the most important sources of mineral raw materials.

At present, there is no strict and generally accepted method of analysis of the distribution of regular patterns for minerals and of making maps reflecting these regularities as a basis for exploration. However, a synthesis of our experience in this field, and a compilation of practical instructions — short of a manual — with consideration given to specific aspects of the problem, is necessary even now. Such instructions should be worked out first for intermediate-scale metallogenic maps of ore regions in fold provinces, ancient platforms, and closed regions; for intermediate-scale coal and oil maps of individual basins and provinces; and for a detailed mapping of the regular patterns of distribution of minerals in areas where they are most highly concentrated.

The problem of regular patterns in the distribution of mineral deposits throughout the Soviet Union can be tackled only by collective action of geologists from both scientific and industrial organizations. In this connection, it is well to recall that last year's scientific session on metallogenic and exploration maps recommended the organization of special metallogenic exploration parties in all provincial Geological Administrations, staffed by qualified geologists. The Session deemed it desirable that the making of metallogenic exploration maps should become a part of the routine work of geologic prospecting parties in their plat-by-plat surveying at 1:100,000 to 1:200,000 scale. Inasmuch as the problem of regular patterns in the distribution of minerals has been recognized as the leading one, all our scientific research institutions, both academic and affiliate, should give it the central place in their schedules and assign to it their leading scientists.

A rational way of collective dealing with this problem is a recommendation for the creation of a special Interdepartmental Scientific Council for the study of regular patterns in the distribution of most important minerals, as well as central and local committees. The Council is based on the Commission on Regular Patterns in the Distribution of Minerals, which was headed by N.S. Shatskiy and which has laid the foundation for collective study of this problem on a representative basis. Participating in the Council are representatives of the Academy of Sciences, U.S.S.R., of the Union Republics academies, the Ministry of Geology and Mineral Conservation, and the schools of higher learning. The Council, headed by Academician D.I. Shcherbakov, coordinates the activity of five committees on the study of various mineral groups. These committees are as follows:

1) sedimentary minerals (Academician N.S. Shatskiy, leader);

2) endogenic minerals (Professor G.A. Sokolov, leader);

3) rare and dispersed minerals (K.A. Vlasov, Corresponding Member of the Academy of Sciences, leader);

4) oil and gas (M.F. Mirchink, Corresponding Member of the Academy of Sciences, leader);

5) coal (I.I. Gorskiy, Corresponding Member of the Academy of Sciences, leader).

In addition, local provincial committees have been created for the study of regular patterns in the distribution of minerals: for the Northeast U. S. S. R. (I. Ye. Drapkin, leader); for Siberia (V. A. Kuznetsov, Corresponding Member of the Academy of Sciences); for the Urals (A. A. Pronin, leader); for Kazakhstan (Academician K. I. Satpayev, leader); for Central Asia (Kh. M. Abdullayev, Corresponding Member of the Academy of Sciences); for the Ukraine (Academician V. G. Bondarchuk of the Ukrainian SSR).

A prerequisite in the standard academic procedure is a timely publication of scientific and practical results. The following publications in this field would be desirable: 1) the papers initiated by N.S. Shatskiy; 2) information bulletins; 3) a series of manuals on making maps of the known and assumed distribution of various mineral groups, at different scales.

In connection with the fact that this problem has been recognized as the central one in the field of geology, our geologic magazines should give it considerably more space and attention than has been done hitherto. Finally, the order of printing should be established for maps of the known and assumed distribution of minerals.

The concentration of the collective effort of large groups of Soviet geologists on the essential and fascinating problem of regular patterns in the distribution of minerals in the crust will undoubtedly lead to discovery of new and rich mineral deposits, thus contributing to the strengthening of the material basis of communism in our country.

# SOME GEOLOGIC RESULTS OF STUDY OF THE ABSOLUTE AGE OF ROCKS[1]

by

G. D. Afanas'yev

## INTRODUCTION

A clear understanding of the age of igneous complexes and of the sequence of formation of their components is essential in the solution of many problems in petrogenesis and ore-making related to igneous processes.

The coincidence in the formation time of chemically similar rock types which represent different geologic bodies, by virtue of the manner of their formation (intrusives, extrusives, effusives), may suggest a common magmatic source for these multifacial manifestations of a discrete igneous tectonic cycle.

An exposition of synchronism in multifacial igneous formations is helpful in working out structures, textures, mineral features, and accompanying processes — as criteria for speculating on the depth at which the intrusions were formed.

The age determination of igneous rocks may be used as a basis for a time scale which will facilitate the age determination of some metamorphic sequences. The same method may be used in determining the time of metamorphism of sedimentary rocks, with the time of their deposition determined from syngenetic minerals.

In recent years, thanks to age studies, it became possible to get an idea of superimposed processes in rocks.

Academician V.I. Vernadskiy was among the first to appreciate the tremendous scientific and practical importance of radioactive methods of age determination for geologic formations. He perceived the basic problem in radiogeology as the determination of the absolute age of geologic phenomena, based on the process of radioactive decay and on the accumulation in minerals and rocks of the end products of decay — lead and helium — in quantities proportional to the time elapsed.

Modern achievements in physics and mathematics in the study of the atom have shown that geologic objects (rocks and minerals) subject to visual study (with the naked eye and microscope) are composed of particles whose evolution can be perceived only by physical and radiochemical methods.

Even as a rock or mineral undergo changes in the course of the geologic development of the earth, individual atomic components of matter also undergo an evolution.

This evolution of the atoms of the crustal matter reveals a new and very important realm of geologic facts. Reflected and fixed in the structure of atoms is their age, i.e., the formation time of minerals and their metamorphism, which is very important in the understanding of the evolution of magmatic processes.

We are now at the initial stage of a new branch of geology which in time will undoubtedly blossom forth as a new science of the earth. The present stage of geology and petrology is marked by the realization that a reevaluation is necessary for some of our long-accepted ideas.

Classic hypotheses in the field of petrogenesis, based on the premise of an everlasting juvenile magma, or on the presence of two magmas in the crust and on the origin of diversified rocks from a differentiation of various types of magma, are unbalanced by the weight of new geologic facts, experimental data, and geophysical observations.

The orthodox concepts of magmatists are punctured by facts suggesting a long evolution of granitoid massifs, not necessarily the products of crystallization resulting from a single penetration of molten magma. Ever more clear in the formation of granitoids is

[1]Nekotoryye geologicheskiye rezul'taty issledovaniy absolyutnogo vozrasta gornykh porod.

the part of metasomatic processes which accompany igneous phenomena.

The main cause of discord among geologists, and a partial cause of their erroneous assumptions, is the fact that the true sequence of processes often remains obscure. This is why geologists should adopt absolute age methods and other achievements of modern physics, instrumental in understanding the evolution of matter in the crust.

We are not so much interested in the age of a rock, by itself, as in the position of an ore and of the rock to which it is related in time and space; this is the only way toward well substantiated theories of petrogenesis and toward a practical application of scientific results.

Undoubtedly, the future progress in geology will be based on rigorously established geologic facts, with a wide application of study in the field of isotope geology in close cooperation with geologists and geophysicists, and finally on experiments in the synthesis of rocks and minerals at high temperatures and pressures, with participation of volatiles.

More accord would have been achieved as to the origin of alkali rocks and granite, on the relationship between mineralization and individual intrusions, and on more correct understanding of the history of geologic development of individual regions, if positive proof had been obtained for the temporal and spatial sequence of all the complex processes and displacements undergone by igneous material over long periods of time. Of substantial help in this respect might be one of the branches of isotope geology — a study of absolute age.

The term, absolute age, does not necessarily mean that a given figure is the age of a mineral. The experience of about five years in a fairly wide application of the absolute age determination method has demonstrated that a rock, in the course of its existence of some billions of years, could have undergone changes distorting the true ratios between mother substances and the products of its decay. Such distortions are possible in both the uranium-lead and the potassium-argon methods; the situation is less clear as regards the rubidium-strontium method.

In a systematic geochronologic study, and in that combined with petrographic work, as well as in a combination of methods, these distortions can be detected and accounted for by another method — that of determination of the time and nature of metamorphism in a rock. It also should be kept in mind that any radiologic method gives the age of a single mineral, while a rock may contain minerals of different ages.

On the basis of experience, it can be definitely stated that methods of absolute age determination are suitable for dating and differentiation of igneous formations when the latter have not undergone recrystallization in subsequent metamorphism, or a partial disturbance of crystalline lattices of their component minerals, in the migration of some of these components out of the complex of radioelements or out of the products of their decay. Recent study both home and abroad demonstrates the feasibility of determining the time of metamorphism in sedimentary sequences which often is very important in geologic conjectures. Finally, a study of glauconite, initiated in the U.S.S.R. in 1955, has shown that radiologic methods of age determination can be used in the dating of sedimentary rocks chiefly in platform provinces, because the crystalline lattice of glauconite is less stable where metamorphism occurred, especially because of the thermal factor.

The work of recent years has convinced some investigators that the absolute time scale of J. P. Marlbrough needs refining to the extent of increasing the age of individual geologic systems by 7 to 10%. Further study in the development of a geochronologic scale should determine more precisely the true duration of geologic periods.

Especially important in applied geology are the initial and encouraging results of dating the mineralization process from minerals originating during the formation of ore deposits.

## THE PRINCIPAL METHODS

The lead method is based on the decay of elements in the uranium, actino-uranium, and thorium series, with stable isotopes $Pb^{206}$, $Pb^{207}$ and $Pb^{208}$ accumulating in radioactive minerals. Having determined the isotope composition of lead liberated from a mineral, and knowing its content in the mineral as well as the content of uranium and thorium in it, the age can be computed from ratios $Pb^{206}/U^{238}$, $Pb^{207}/U^{235}$, $Pb^{207}/Pb^{206}$, and $Pb^{208}/Th^{232}$.

The age computation from these four ratios has become possible only after the application of mass-spectrometric determinations of the lead isotope composition.

Fairly numerous data have been obtained with the lead method, in the Soviet Union, in recent years. The work has been done

chiefly at the V. G. Khlopin Radium Institute and at the V. I. Vernadskiy Institute of Chemistry and Geochemistry, Academy of Sciences, U. S. S. R. Work in these institutions has shown that the most reliable data are those by the lead method which give the same results, within the limit of error, from all of the above ratios. However, a number of computations from different ratios gave different results, caused chiefly by migration of the mother substance and of the products of its decay.

It may be assumed from the results so obtained that lead migrates more readily than the mother substance from radioactive minerals, and specifically from uraninite, which is the main factor in the lowering of their determined age.

The argon method of age determination is based on decay of the radioactive potassium isotope, wherein the decay of the $K^{40}$ nucleus proceeds by capturing an electron from the surrounding electron shell. As a result of this capture, argon of mass 40 is formed. The argon method is very important in geology because it can be used in determining the absolute age for widely distributed minerals.

In computing the age of minerals from radiogenic argon accumulated in them, it is necessary to know both the content of K-capture and that of its $\beta$-decay. Until recently, laboratories of the Soviet Union used $6.02 \times 10^{-11}$year$^{-1}$, for the K-capture constant value, as determined in the Precambrian Geology Laboratory, Academy of Sciences, U. S. S. R.; and $4.9 \times 10^{-10}$year$^{-1}$ for $\beta$-decay constant, as an average of many determinations by different authors.

Recently, a number of laboratories have changed to $\lambda_k = 5.50 \times 10^{-11}$year$^{-1}$ and $\lambda_\beta = 4.72 \times 10^{-11}$year$^{-1}$.

The Carnegie Geophysical Laboratory (the 1956-1957 report of the Laboratory) used $\lambda_k = 0.557 \times 10^{-10}$year$^{-1}$ and $\lambda_\beta = 4.72 \times 10^{-10}$year$^{-1}$, which corresponds to the ramification value $\lambda_k/\lambda_\beta = 0.118$. For this reason, the age values obtained until recently at the Carnegie Laboratory are somewhat higher than those obtained in the U. S. S. R.

To determine the nature of argon liberated from K-minerals, its isotope composition is determined. Radiogenic argon should consist fully of $Ar^{40}$, without any lighter $Ar^{38}$ and $Ar^{36}$, typical argon of the air.

As shown by experience, argon liberated from K-minerals is chiefly radiogenic. The admixture of air argon in ancient minerals is 1 to 2%, with 5 to 10% in younger minerals of the total radiogenic argon content. Most of the air argon gets in the gas sample during its separation from minerals. In order to avoid errors in age determination, the isotope content of argon should be checked in each sample.

It should be pointed out, however, that mass-spectrometric control is not always an absolute criterion of reliability of data obtained: in such minerals as quartz, beryllium, and some plagioclase, there may be an excess of $Ar^{40}$ occluded by minerals in the process of their crystallization. Other criteria will have to be used in that instance.

Results obtained on micas are in fair agreement with the values of age obtained by the lead method on uraninite and monazite.

According to results from various laboratories, feldspars are less suitable for age determination.

Exaggerated age values have been obtained on micas, in a few instances, which may be explained by older mica having been inherited by a pegmatite or other rock. However, this requestion remains moot and requires special consideration.

The strontium method is based on radioactivity of the $Rb^{87}$ isotope whose content in rubidium is 26.5%. As a result of decay of $Rb^{87}$, radiogenic $Sr^{87}$ is accumulated in minerals. In order to determine the age of minerals with the strontium method, it is necessary to know the content of both rubidium and radiogenic strontium. These isotopes are best and most rapidly determined by the isotope dilution method, based on the introduction into a substance analyzed, of a rigorously determined amount of an element with an isotope composition different from its isotope content in the earth's crust. Then, knowing the amount of the stable isotope introduced as a tracer, the amount of the element in question can be determined in the sample, by the change in the isotope ratio of the mixture.

At the present time, the strontium method is being developed in a number of scientific organizations of the Soviet Union.

Turning now to the potential of these methods for absolute age determination for geologic purposes, it must be stated that the K-Ar and the Rb-Sr methods are the most promising; the combination of both methods results in comparable and fairly reliable figures.

The maximum emphasis should be put on the study of potassium-bearing minerals (micas, feldspars) in terms of their geologic

position and the paragenesis of subsequent superimposed processes, prior to the study of their age by different methods based on radioactive decay of elements. An intensivication of experimental study is also necessary sary, followed by a detailed optical and x-ray study of minerals in question; this will reveal the significance of rebuilding the mineral structure in the loss of radiogenic argon.

In 1955, the author [2] noted the complications arising in the determination of absolute age related to the lack of precision in the method of potassium determination then used (the presence of rubidium, hydration and oxidation of micas in their processing prior to chemical analysis, etc.). This was especially true when potassium was present in small quantities, which could result in considerable deviation in the absolute age figures. It was shown at the same time that porphyritic inclusions of K-Na-feldspar, which are porphyroblastic (metasomatic) formations in many granitoids, were older than the material in which they had developed. In other words, the discrepancy in the age figures are caused — beside the technical errors — by the formation time differences for individual minerals in granitoid rocks.

Further study by the K-Ar method, of minerals and rocks of different geologic ages and distributed in different geologic structures has shown that this time difference in the formation of individual minerals in a rock was accompanied by migration of argon, which took a different course in different minerals, because of the subsequent effect of younger magmatic masses.

For some igneous complexes of Northern Caucasus, such as those formed at the time of intrusion of the rocks under study, and not altered by the superimposed effect of younger magmatic masses, the age figures for muscovite and perthitized microcline from the same pegmatite vein turned out to be identical (190 million years) and corresponding to geologic data.

These rigid Caucasian massifs are cut by small intrusions of diorite and anorthoclase granite, and are transgressively overlain by Triassic rocks, including a basal conglomerate of the same diorite fragments. The age of an overall sample of this diorite was determined as 220 million years, and of its feldspathic fraction at 215 million years. The feldspathic fraction of granites from the peripheral part, with material of enclosing rocks carried away during the intrusion, gave an age figure of 215 million years. It is clear, in this instance, that geologically post-Early Paleozoic but pre-Triassic intrusives and their feldspathic fractions were not subject to "rejuvenation" of feldspar.

Pebbles of pegmatoid microcline granite from Triassic conglomerate, petrographically identical with Upper Paleozoic vein granite from other Caucasian localities, turn out to be 210 million years old. It follows that the Triassic conglomerate indeed carried pre-Triassic granite, rather than "Jurassic," as could have been surmised from the age determination for microcline which has lost 20 to 25% of its radiogenic argon in perthitization.

Along with these data which apparently inspire full confidence for the absolute age figures obtained both on micas and feldspars, as well as on overall rock samples, there is a series of repeated measurements which suggest the effect of superimposed geologic processes on the preservation of radiogenic argon in minerals; in rejuvenating a mineral, such an effect obscures the time of its formation. On the other hand, the same figures, considered simultaneously with a penetrating petrographic study of the subject rock, may be helpful in determining the time of superposition of a given geologic alteration of the rock, connected with an influx of substance or with some physical processes.

Experiments have shown that, in all instances of an obvious superposition of high-temperature processes, both mica and K-feldspar lose some part of their radiogenic argon; it appears that during comparatively high-temperature effects, mica retains more argon than the feldspar.

An almost 100% migration of accumulated argon probably takes place in a protracted and high-temperature heating, as in the effect of a proximate intrusion. For instance, Lower Paleozoic gneiss from the contact halo of a Tertiary intrusion was found to have an age close to that of the intrusion (60 million years). The same is true for xenoliths of ancient granite.

All this goes to show that the K-Ar method, as applied in the age determination of a single mineral, without a penetrating knowledge of the geology and petrology of rocks under study, is not valid for differentiation of extrusive formations in fold provinces, whose igneous activity has had a complex history.

At the same time, the application of the K-Ar method in obtaining a large number of figures, with a parallel and comprehensive petrologic study of extrusive formations, undoubtedly will allow a well substantiated age differentiation of igneous rocks and their derivatives, and will bring forth the sequence and nature of many petrogenic processes.

It may be assumed that an age figure,

obtained on a well-averaged or even random sample, with an adequate measurement of the amount of radiogenic argon and potassium, will give a correct idea of the geologic system to which the sample belongs. This follows from the fact that the difference in age of minerals, and the superimposed processes promoting the migration of argon, are most often connected with the evolution of a single intrusive complex, whose duration seldom exceeds 50 to 60 million years. This generally constitutes an adequate basis for geologic conjectures, often unattainable through conventional geologic methods.

The age distortion, connected with the superimposed effect of a magmatic mass or new intrusive cycles, is manifested usually in a specific structural environment, accompanied by specific petrographic phenomena, both always determinable by detailed petrologic study. In such instances, the K-Ar method, while not giving the true age of a rock, will be instrumental in determining the character of past processes.

## SOME FINAL DATA ON THE ABSOLUTE AGE DETERMINATION FOR GEOLOGIC FORMATIONS OF PROVINCES OF THE SOVIET UNION AND OF FOREIGN COUNTRIES[2]

### Precambrian Formations of the Baltic and the Ukrainian Crystalline Massifs

Research in the absolute age determination of Precambrian crystallines in the Ukrainian and Baltic massifs has been carried on for some time in the laboratories of the Academy of Sciences, U.S.S.R., Radium Institute, Institute of Geochemistry and Analytic Chemistry, Laboratory of Precambrian Geology, and the All-Union Scientific Research Geological Institute.

Different minerals were studied by different methods. The difficulty of differentiating Precambrian crystallines is obvious.

As a result of painstaking effort of the above-named research organizations, Precambrian crystallines have been differentiated into several age groups (in million years), as follows:

Baltic Shield Granite:

| | |
|---|---|
| Rapakivi | 1620–1640 |
| Karelids | 1640–1870 |
| Belomorids | 1710–2020 |
| Katarkheya (?) | 1820–3250 |

Ukrainian Massif[3]

| | |
|---|---|
| Uman granite | 1450 |
| Rapakivi granite | 1650–1750 |
| Tokov granite | 1800? |
| Gneisses, crystalline schist | 2000 |

A number of figures was obtained in the laboratory of E. K. Gerling for Precambrian micas of the Baltic shield, by the Rb-Sr method, in fair agreement with those obtained by the K-Ar method.

### The Urals

The very first determinations of absolute age for geologic formations of the Urals by the K-Ar method (L. N. Ovchinnikov and others) gave very interesting figures.

Igneous formations (in million years)

I. Precambrian stage

| | |
|---|---|
| Berdyaush Rapakivi | 1060 |
| The Shagir Massif | 1200 |

II. Middle Paleozoic stage (Caledonids)

| | |
|---|---|
| Massifs Tagil'sk, Kushvinsk, Kaldin, Auerbakhovsk, Magnitogorsk | 365-385 |

III. Upper Paleozoic stage (Hercinids)

| | |
|---|---|
| Massifs Verkh-Isetsk, Murazino-Alabash, Il'menogorsk | 245-290 |

IV. Mesozoic (?) stage

| | |
|---|---|
| Basalt tuffaceous breccia (Yelkino) | 167 |
| Liparite (Kushmurin brown coal deposit, Upper Triassic) | 164 |

According to L.N. Ovchinnikov, these igneous activity epochs are correlative with metamorphic changes in the emplacing rocks. More specifically, sericite schist of the Severnyy, Krasnogvardeyskiy, and Yas'vinskiy pyrite deposits are 320 to 340 million years old, which corresponds to the age of

[2]The figures below are computed on the basis of $\lambda_k = 5.50 \times 10^{-11}$year$^{-1}$; $\lambda_\beta = 4.72 \times 10^{-10}$year$^{-1}$.

[3]Works of N.P. Semenenko cite a more detailed differentiation for Precambrian of the Ukrainian shield, with somewhat different age figures.

Caledonian massifs in the Urals.

Metamorphic formations of the Upper Paleozoic, designated by L. N. Ovchinnikov, present a more complex picture. It is probable that the effect of Upper Paleozoic metamorphism was superimposed here on rocks altered by Middle Paleozoic metamorphism.

## The Caucasus

Different structural zones of the Greater Caucasus carry igneous and metamorphic formations of four major stages of a complex igneous activity (age in millions of years):

| | | |
|---|---|---|
| 1. | Rocks enclosing the Urushten igneous complex (crystalline schists) | over 400 |
| 2. | Urushten igneous complex (Middle Paleozoic) | 375–320 |
| 3. | Hercinian intrusions | 255–190 |
| 4. | Mesozoic igneous activity | 150–100 |
| 5. | Tertiary igneous activity | 90–15 |
| 6. | Quaternary igneous activity | Lavas, extrusions of liparite and andesite |

Within these age groups, there is a very complex picture of the formation of individual massifs, their vein series, and of phenomena of metamorphism, metasomatism, and associated mineralization.

Recent study of sedimentary formations in the Caucasus have revealed the following interesting facts:

1. In the area of development of younger igneous activity (Jurassic and Tertiary), Silurian and Devonian phyllites have been found consistently to have an age of 160 to 170 million years. These figures reveal the age of metamorphism in schist; a complication has been introduced by the incomplete migration of older radiogenic argon.

2. It has been determined that Jurassic flysch-like metashale of the northwestern Caucasus give an age of 240 to 260 million years, in every instance. This is the age of Paleozoic terrigenous material which did not undergo any superimposed metamorphism.

3. Cretaceous glauconite from unmetamorphosed deposits gave a figure of 80 to 70 million years, with 70 million years for montmorillonite clay from Eocene trachite tuff.

The total data from the absolute age determination for igneous, sedimentary, and metamorphic rocks of the Caucasus makes it possible to correct current ideas on the geology of the Caucasus and its mineral wealth.

## Central Asia

From the data of D. I. Shcherbakov, A. Ya. Krylov, and others, the following can be identified among igneous rocks of Central Asia, at the present time (age in millions of years):

| | | |
|---|---|---|
| 1. | Caledonids of the Terskey Alatau, Talass Alatau, etc. | 365–330 |
| 2. | Hercinids of the Kuramin complex; the Shaydan granite | 300–190 |

## Central Kazakhstan

Most figures for the Central Kazakhstan granitoids fall within a 320 to 375 million year range. Most of these granitoids are supposed to be early Hercinian ($C_2$?), with some of them Devonian ($D_2$?). Four age figures, also associated with early Hercinian, fall within a range of 290 to 300 million years.

## Trans-Baykal Region

Data of Ye. M. Dolomanova have confirmed the Mesozoic-Cenozoic age, 85 to 128 million years, for granites of this province.

## Far East

The following age has been determined by N. I. Polevaya for the Maritime Region (Primor'ye) (in millions of years):

| | | |
|---|---|---|
| 1. | Paleozoic igneous activity — the Shmakov, Grodekov, and Voznesensk granites | 320–215 |
| 2. | Early Mesozoic igneous activity — Bikin, Sootukhe, Koshkarovo | 170–140 |
| 3. | Cenozoic igneous activity | 115–30 |

According to Ye. K. Ustiyev, the age of extrusive rocks from the Okhotsk-Kolyma province (Anmandikan, Greysha, Alan-Su rivers) falls within the 250 to 295 million year range.

The Chukotsk Peninsula extrusives, studied at the Dagestan Affiliate, Academy of Sciences, U. S. S. R., are associated with the Cenozoic igneous stage, since their age is 40 to 110 million years.

Foreign Countries

In western countries, especially in the U. S. A., research in the field of absolute age determination has also been successfully developed.

Simultaneously with our observations, it was noted in the U. S. that a superposition of processes or a difference in the mineral formation time results in a distortion of the ratio of the mother substance to the products of its radioactive decay, which leads to a distortion in the absolute age figures or to their difference, depending on the method and material used. A number of results of this study have been published in the Director's report of the Carnegie Geophysical Laboratory for 1956-1957.

The age determination of mica from granite of western states (The Cordilleran system of Arizona, Colorado, Wyoming, etc.), by the K-Ar and Rb-Sr methods resulted mostly in comparable figures. The age determination of rocks on Sudbury micas, by the K-Ar and Rb-Sr methods, also gave interesting figures which have confirmed the assumed sequence of igneous formations, and a fair agreement in figures obtained by the two methods.

Also interesting are the figures obtained on zircon from both young and old granite, and their correlation with figures obtained by the Rb-Sr and K-Ar methods on mica of granite from Schwartzwald, the Vosges, and Canada. It appears that data obtained on zircon by the U-Pb method are less reliable, because different isotope ratios give at times considerably divergent results.

A number of papers on absolute age were read before the Volcanological Association of the Eleventh General Conference, International Geodetic-Geophysical Union, in 1957.

L. T. Aldrich, G. R. Tilton, and G. L. Davis reported on the study at the Carnegie Institute: In their opinion, the age determination results obtained by the U-Pb and Th-Pb methods for zircon from monazite and columbite-titanite vary to such an extent as to cast a doubt on the use of these minerals for this purpose.

S. S. Goldich, H. Baadegaard, and A. O. Niir, in their paper, The Age Study by the $Ar^{40} = K^{40}$ Method, cited the following data: in a group of unaltered granites and granite-gneisses, of an age varying from 500 to 2500 million years, feldspars displayed a consistent argon deficiency of 36%, as compared with micas. Dating by both feldspar and mica is feasible in those provinces where metamorphism has not been superimposed on primary crystallization. Repeated analyses of pulverized feldspar (40 to 60 mesh) did not detect any argon loss for 4 to 12 months. It has been shown that stilpnomelane is not suitable for age determinations.

According to P. M. Harley (Information on Age Measuring by the Ar = K and Rb = Sr Method), a comparison of age determinations by the K-Ar and Rb-Sr methods shows general agreement. The discrepancy is connected with the effects of metamorphism rather than with the excess argon, weathering, or operational errors. G. Fowl and G. L. Tilton (Age of Some "Hercinian" Granites of Europe) have determined the age of granite rocks in a "Hercinid chain" from areas of Oslo, Schwartzwald, the Vosges, Alps, and the Central Massif. Ratios U/Pb, Th/Pb, and Pb/Pb were determined on isolated zircon, and K/Ar and Rb/Sr in biotite. The determination results on zircon, in every instance, had innate divergences showing that the post-crystallization lattice of these zircons had been disturbed. Thus, the age of these rocks cannot be determined satisfactorily from the study of zircons alone.

The age of biotites investigated, as determined by both the Rb-Sr and K-Ar methods, coincided in every instance, giving figures of about $345 \pm 5 \times 10^{-6}$ million years. The stratigraphic age of these rocks has been determined as Westphalian (pre-Middle Carboniferous); usually they are assigned to the Dinantian (Lower Carboniferous). However, according to the Holmes scale, the measurements indicate a Middle Silurian age. The conclusion is that either the time scale or the stratigraphic determination is wrong. This author suggests that the mica in question might correspond to an earlier igneous rock which has contaminated the granite.

Interesting data were obtained by G. G. Wassenburg on the age of the Glenarm series; micas from its pegmatites and metamorphic rocks yield comparable ages of 350 million years.

There are more than 2000 or 3000 age determinations in the Soviet Union, chiefly by the K-Ar method; still, many provinces, especially in the eastern part of the Soviet Union, are hardly touched by this study. Such is the vast province of trap volcanic activity, our own Kimberley area. Igneous formations of the Altay, Kuznetsk Alatau, and Sayan-Khingan, too, are still waiting for their absolute age to be determined.

A differentiation of the development stages of igneous activity throughout this country, by proper geologic methods and by absolute age determinations, will facilitate the attack on

problems of general geology and of petrogeny and orogeny.

Even the few figures on hand at the present time, and the igneous stages designated from them in various structural provinces of the U. S. S. R., show that igneous and metamorphic rocks of several igneous tectonic cycles participate in the formation of such ancient fold provinces as the Urals and younger ones such as the Caucasus and the Pacific coast. The relatively young fold provinces such as the Caucasus and most likely the Maritime Region, were sites of periodically surging igneous activity, for a long period of time, of the order of 500 million years.

One of the objectives of future petrologic study undoubtedly will be a study of the evolution of igneous activity in time, for definite geostructural units, and a correlation of nearly contemporaneous igneous complexes in different structures.

Such a comparative study, combined with a study of metallogenic features of igneous bodies and of their geochemistry, will undoubtedly become a basis for petrologic syntheses on the evolution of igneous activity throughout the U. S. S. R. and for a better insight into the origin of igneous and metamorphic rocks and of associated ore deposits. Many problems in geology, including that of the structure of the crust, will be expedited by the application of the method of absolute age determination.

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Received June 8, 1959

# THE STAGES OF DEVELOPMENT OF COPPER-NICKEL MINERALIZATION IN THE NITTIS-KUMUZH'YE-TRAVYANAYA MASSIF[1]

by

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New data were obtained recently on the formation of the Nittis-Kumuzh'ye copper-nickel vein deposit in the Monche tundra. An analysis of the textural and structural features of the ores leads the author to the conclusion that three stages of mineralization can be identified: the magnetite, the pyrrhotite, and the chalcopyrite stages.

* * * * *

Hydrothermal ore formation by stages and the role of intramineralization tectonics has attracted much attention in recent years.

With regard to igneous ore deposits, including the copper-nickel sulfide deposits genetically related to basic and ultrabasic rocks, the topic of stage development has been but slightly touched upon and not adequately presented in literature. Important in this respect are data obtained from the Nittis-Kumuzh'ye vein ore deposit in the Monche tundra.

As early as 1947, V.K. Kotul'skiy [1] noted that each ore vein has its own distinctive features. They are expressed first in the quantitative relationships between principal minerals; second, in the textural features of ores.

According to V.K. Kotul'skiy, features of mineral composition and texture are a result of differentiation of sulfide magma, in its progress along a complex system of fractures. The original lack of homogeneity in the sulfide magma, according to him, could hardly have played a decisive part in the diversification of veins.

Later on, G.V. Kholmov and D.A. Shil'nikov [4] recognized two stages in the vein mineralization — a magnetite and a sulfide — which they associated with different stages of intrusion along the fractured zone by a magmatic ore melt. The mineralization stages were separated by tectonic shifts which caused enlargement or reopening of vein fractures. Ore material separated from the ore magma at that time was deposited in these reopened fractures and in lower pressure zones, brought about by repeated breaks.

In recent years, in connection with the exploration of the flanks and of lower levels of the Nittis-Kumuzh'ye deposit, new and interesting data have been obtained which clarify our concepts on its origin and formation. The results of the 1955-1957 study by this author are set forth below.

## BRIEF DATA ON THE GEOLOGIC STRUCTURE OF THE DEPOSIT

Geologic descriptions of this deposit can be found in a number of published papers. Therefore only the most general and essential information is given below.

This deposit is associated with the Nittis-Kumuzh'ye-Travyanaya massif, trending northeast and representing a western branch of the structurally complex Monchegorsk pluton. The massif plunges gently, preserving its original stratification, and is made up of pyroxenite (bronzitite), olivine pyroxenite, and peridotite. Its bottom part is formed by feldspathic rocks: feldspathic peridotite, coarse-grained pyroxenite, gabbro-norite, and quartz-biotite norite.

The ore veins are located in olivine pyroxenite, in the axial part of the massif, and trend approximately parallel to its long axis. The ore field consists of several tens of veins, varying widely in size, along and across the strike. In the central part of the ore field, the veins trend almost meriodionally,

[1] Stadiynost' zhil'nogo medno-nikelevogo orudeneniya massiva Nittis-Kumuzh'ye-Travyanaya.

veering northeast and southwest in its northern and southern parts. The veins dip steeply (80° to 90°) toward the axis. Their thickness and length decrease with depth; nevertheless, ore-bearing fractures are traceable to the limits of penetration; it is possible that they persist to the base of the massif.

A zone of essentially chalcopyrite ore showings has been discovered by the Monchegorsk prospecting party, on the continuation of the vein ore zone, down dip. It is represented there by isolated small vein-like to pocket-like ore bodies, accompanied by sulfide incrustations.

The chalcopyrite ore showings are located in plagioclase peridotite where they form a comparatively narrow band extending along the massif. It is separated from the upper ore veins by an interval where some boreholes have penetrated small vein-like bodies of copper-nickel ores.

The chalcopyrite ore deposits can be divided into two groups in relation to the enclosing rocks.

Group one includes ores associated chiefly with zones of shattering and schistosity in plagioclase peridotite. These zones are made up of amphibole-chlorite-talc rocks. The massive chalcopyrite bodies associated with them are usually vein-like, with veinlets, pockets, and lumps of ore, elongated because of their occurrence in the planes of schistosity. The structure of such sulfide accumulation is normal, granular, without any cataclasts. The bodies of massive ore carry numerous inclusions of a schistose amphibole-chlorite-talc rock and of its component minerals. Massive ores in the zones of shattering and schistosity are accompanied by incrustations of sulfides in altered peridotite.

Group two is formed by chalcopyrite ores associated with dikes of gabbroid (chiefly gabbroic pegmatite) rocks. Here, the massive ores are associated with the most deformed segments of dikes. They carry numerous inclusions of gabbroic pegmatite rock and of its component minerals. The massive ore also is accompanied by inclusions of chalcopyrite.

## STAGES OF VEIN MINERALIZATION

Ore veins of the Nittis-Kumuzh'ye-Travyanaya massif are filled with massive ores whose main minerals are pyrrhotite, pentlandite, chalcopyrite, and magnetite. Decidedly subordinated are pyrite, ilmenite, cubanite, sphalerite, galena, and platinum group minerals.

The following varieties of ores are identified on the basis of their mineral composition and paragenetic mineral associations: pyrrhotite-pentlandite ore (principal), magnetite, and chalcopyrite.

Apophyses of veins, their constrictions, and the intersection of dikes are made up chiefly of chalcopyrite ores, while the magnetite ore veins are thin, short along the strike and the dip, and are usually located in the zones of shattering and schistosity of olivine pyroxenite and peridotite. Several essentially magnetite veins are known in this deposit.

Mining geologists have determined that the amount of magnetite ores in veins increases with depth. In deeper levels, magnetite ores make up sizable segments of the shattered zones.

By comparing data from individual ore veins, it is possible to discern a number of common features in them, thereby shedding light on the general conditions of formation of this deposit. Taking into account the data of other investigators, the author believes it possible to designate three stages of mineralization in the process of formation of vein ore: the magnetite, the pyrrhotite-pentlandite, and the chalcopyrite, separated by intramineralization shifts, by reopening of vein fractures, and by a partial fragmentation of earlier formed ores.

The first stage is marked by the formation of magnetite ores without the accompanying sulfide minerals. The enrichment of ores by sulfides took place only by the superposition of later stages. The presence of nickel in magnetite, determined by spectrographic analysis, is apparently due to the very fine pentlandite inclusions in it. The deposition of magnetite ores proceeded by the filling up of fractures and partly by replacing the gabbroic pegmatites which occupied the same system of fractures as the ore veins. Those gabbroic pegmatite segments which had been tectonically disturbed were subject to replacement. Some segments of magnetite ore exhibit a brecciated texture caused by the presence of gabbroic pegmatite fragments cemented with magnetite.

The second stage, more intensive and extensive, was expressed in the formation of pyrrhotite-pentlandite ores. A study of vein structure in mining work has established that the making of new fractures was initiated after the deposition and crystallization of magnetite ores had been completed.

The deposition of pyrrhotite-pentlandite ores, like that of the magnetite, occurred not only by filling up open hollows but by replacing the magnetite ore and the gabbric pegmatite, as well.

Observations in shafts have shown that magnetite ores were locally subjected to dynamic stresses (expressed in a cataclastic texture and in a peculiar mylonitization) and to sulfide mineralization.

Sulfides formed isolated veinlets or a network of veinlets in their penetration in the magnetite body, along fractures. Vague and irregular accumulations of sulfides were formed in the further development of this process, with mineralizing solutions penetrating the magnetite body through submicroscopic fractures and penetrating farther into the massive segments. In a still more intensive replacement, magnetite remained in isolated angular or rounded bodies. The textures formed in this process were a result of dynamic stresses on magnetite and of its replacement by later sulfides.

The phenomena of sulfides replacing the gabbric pegmatite are best expressed in the southern segment of the mine field.

Figure 1 illustrates a segment of vein 36, where it changes to a gabbroic pegmatite dike associated with a zone of strongly schistose peridotite.

Some distance away from the dike, the vein shows fragments of gabbroic pegmatite, with inclusions of its component minerals. Their amount increases gradually toward the dike. The vein-dike contact is uneven and sinuous, with pyrrhotite forming a sort of inlets in the gabbro-pegmatite rock. Pyrrhotite inclusions are present in the gabbroic pegmatite, near the vein contact.

Inclusions of the gabbroic pegmatite and its component minerals, chiefly plagioclase, occur also in the central part of the ore field, in deep levels of mining. The evidence is that the replacement of gabbroic pegmatites by sulfides is widewpread.

There is definite evidence of deformation in plagioclase grains. It is expressed in the fracturing of grains, their bending, and in microfaults, which distort the typical polysynthetically twin structure of grains; also in the appearance of pressure twins, and finally in the granulation of grains.

Turning now to the inner structure of ore veins, it should be noted that they often exhibit banded textures, determined by a distinct alternation of magnetite and sulfide bands. Figure 2 presents a segment of the banded structure from a vein. Here we see two magnetite bands, one of them associated with the vein contact with olivine pyroxenite.

Banded structures are expressed not only in an alternation of ores formed at different stages of mineralization; they are present also in vein segments filled with pyrrhotite-pentlandite ores. According to E.N. Yeliseyev, the banded structure of these ores is due to an alternation first of pyrrhotite bands enriched with porphyritic crystals of pentlandite; second, of pyrrhotite bands enriched with pentlandite which is represented here by elongated grains whose long axes are oriented oblique to the direction of banding; third, to the presence in pyrrhotite of pentlandite chains consisting of elongated (idiomorphic with relation to pyrrhotite) grains oriented normal to banding. In a number of veins, the porphyritic grains of pentlandite are associated with their contacts. They are commonly present also in broken fringes along the periphery of rock fragments in a sulfide body. Observations in shafts show that the linear orientation of pentlandite grains was brought about by tectonic movements which also caused plumate fractures in pyrrhotite. That these fractures have been filled is suggested by branching veinlets of pentlandite in pyrrhotite (Figure 3). These facts suggest a later formation of pentlandite (at least a portion of it), subsequent to pyrrhotite. In addition, tectonic movements were expressed in fractures with smooth, slightly corrugated slickensides. These repeated movements brought about the formation of mylonitized ore zones described in detail by V.A. Maslennikov [3].

The third stage of mineralization is marked by a further change in the composition of mineralizing solutions and by the deposition of ores of an essentially chalcopyrite compositon, located separately in ore veins, at different levels. Chalcopyrite ores are commonly associated with the constrictions and sides of ore veins, and the intersections of dikes. The chalcopyrite stage of mineralization is also expressed in the formation of banded ore textures brought about by an alternation of pyrrhotite-pentlandite and chalcopyrite ores. The banded texture was best expressed in the now exhausted eastern segment of vein 16. Here, the boundaries between chalcopyrite and pyrrhotite ores are sharp. The chalcopyrite ores are locally distributed along the contact of magnetite and pyrrhotite-pentlandite ores (Fig. 4). In some veins, the chalcopyrite bands have washed-out boundaries.

In its deposition subsequent to magnetite, pentlandite, and pyrrhotite, the chalcopyrite fills up the space between the grains of these minerals and forms veinlets and penetrations along fractures, commonly replacing these minerals (especially magnetite and pyrrhotite). Small pyrrhotite grains, which are unreplaced relicts of larger grains, as suggested by their optic orientation are fairly common in chalcopyrite.

The common banded texture of chalcopyrite

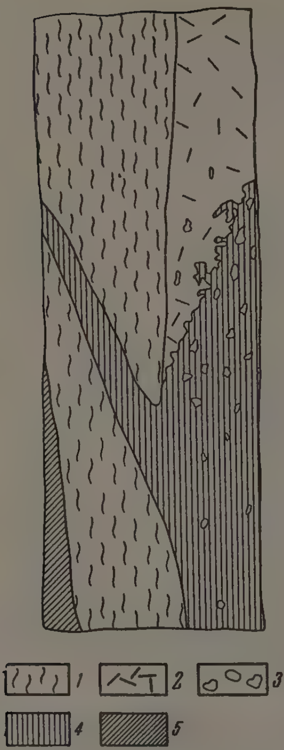


FIGURE 1. Pyrrhotite-pentlandite vein changing to a gabbroic pegmatite dike.

1 -- amphibole-chlorite-talc rock; 2 -- gabbroic pegmatite; 3 -- fragments of gabbroic pegmatite in ore body; 4 -- pyrrhotite; 5 -- chalcopyrite.


FIGURE 2. Grains of amphibolitic and chloritic pyroxene replaced by pyrrhotite.

Specimen from a pegmatoid body of gabbroic pegmatite in the area of Shaft 3 (the 142 m level), 2/3 natural size.

1 -- pyroxene; 2 -- pyrrhotite.

ores and ore veins, as well as their isolated segments and the essentially chalcopyrite mineralization in the lower part of the massif, in the continuation of ore veins along the dip, were the basis for considering the chalcopyrite mineralization stage a separate one. The mineralogic association of the stage is characterized by a marked predominance of chalcopyrite as compared with pyrrhotite and pentlandite, by the presence of the platinum group minerals, and of nickel arsenides, not observed in the pyrrhotite-pentlandite ores.

The deposition of chalcopyrite ores required the presence of favorable ore-controlling structures represented by the segments of ore veins which had undergone dynamic stresses. Tectonic movements, preceding the deposition of chalcopyrite, have lead to the formation of fractures in pyrrhotite-pentlandite ores, with the latter serving as channels for infiltration of essentially copper solutions.

These solutions apparently affected the entire body of pyrrhotite-pentlandite ores. The reopening of fractures, and the subsequent change in the composition of solutions which penetrated them, were probably factors determining the banded structure of ore veins in some segments.

A metasomatic development of copper mineralization where the enclosing medium consists of massive pyrrhotite-pentlandite ore is accompanied by a replacement and redeposition of elements, primarily iron. Despite our inadequate knowledge of the physical and chemical aspects of this phenomenon, we venture a guess that the later deposits of pyrrhotite (second generation pyrrhotite), rather common

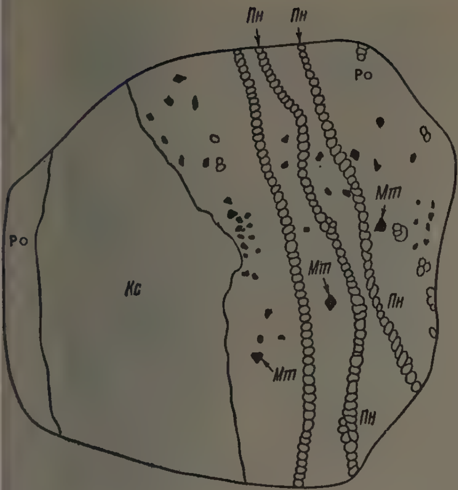


FIGURE 3. Banded structure of a vein, brought about by an alternation of magnetite and pyrrhotite-pentlandite ores.

Sketch of a segment in the drift roof, along vein 36, 142 m level. Scale: 1:20.

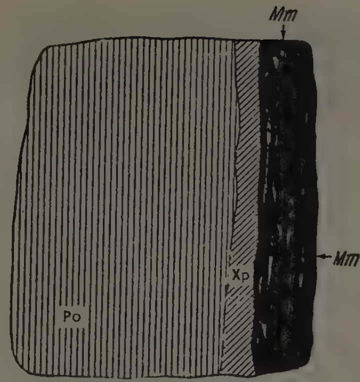


FIGURE 4. Chalcopyrite ore between pegmatite and pyrrhotite-pentlandite ores.

Mm -- magnetite; Po -- pyrrhotite; Xp - chalcopyrite.

in chalcopyrite, appear to be related to this phenomenon. Redeposition of the ore has led to contradictory relationships between the ore minerals.

It should be noted that chalcopyrite ores are distributed unevenly in veins on the whole; they are plentiful in some veins and scarce in some others. The amount of chalcopyrite ore is believed to increase with depth.

Ore-controlling structures favorable for the accumulation of chalcopyrite ores in the lower part of the massif were the zones of shattering and schistosity in plagioclase peridotite represented by schistose amphibole-chlorite-talc rocks, and dikes of gabbroid rocks which had locally undergone dynamic stresses.

The deposition of chalcopyrite ores occurred not only by filling the open hollows but also by replacing the enclosing rocks. Figure 5 illustrates the development of chalcopyrite in association with tremolite, in an amphibole-chlorite-talc rock; Figure 6 shows the development of chalcopyrite in a gabbroic pegmatite.

Spectrographic analysis has shown that chalcopyrite carries a number of admixed elements, probably as fine mineral inclusions. The presence of nickel and cobalt appears to be due to pentlandite inclusions; of zinc and cadmium, to sphalerite; and of silver, to a mineral tentatively believed by us to be native silver. It should be noted that no independent tin minerals have been found in these ores.

A consideration of the stages of ore mineralization reflects the development of a single complex mineralization process. These stages suggest discontinuous ore-making, and a pulsating influx of mineralizing solutions. Such a process of ore formation in the Nittis-Kumuzh'ye vein deposit is not likely to be unique; it probably is typical of other copper-nickel sulfide deposits, genetically related to basic and ultrabasic rocks.

## CONCLUSIONS

1. The diversity in the ore textures and the complexity in relationships between mineral associations in ore veins of the Nittis-Kumuzh'ye-Travyanaya massif are the result of a stage-by-stage development of the mineralization process, in the presence of complex tectonic movements; of a pulsating influx of metal-bearing solutions; and of a variable concentration of sulfur, iron, and other components, in the course of this process.

2. It appears possible to identify three

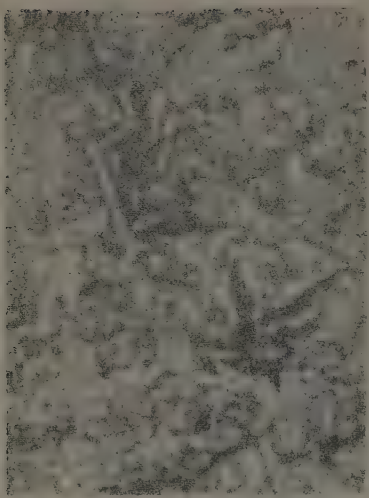

FIGURE 5. Chalcopyrite with tremolite in amphibolite-chlorite-talc rock.

Thin section; shaft 508-a; depth, 392.5 m. Magnification, 18X; nicols parallel. Xp -- Chalcopyrite; Tr -- tremolite.

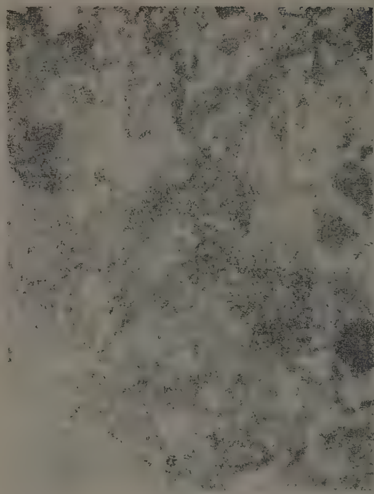

FIGURE 6. Development of chalcopyrite in gabbroic pegmatite rock.

Thin section; shaft 953; depth, 390 m. Magnification, 4.87X; nicols parallel. Xp -- Chalcopyrite; Tr -- tremolite.

stages of mineralization in the process of vein ore deposition: the magnetite, the pyrrhotite-pentlandite, and the chalcopyrite, following each other and separated by intramineralization movements

3. The first stage is characterized by the formation of magnetite ores. The industrially valuable pyrrhotite-pentlandite ores were formed during the second stage. The third stage is marked by the formation of chalcopyrite ores with a higher content of platinum metals and silver in some segments.

4. Depending on the mineralization stage, the ore veins can be divided into those of simple composition which originated in a single stage of mineralization, and those of a mixed composition and of a more complex internal structure. This has been brought about by multiple reopening of ore-filled fractures and by a multistage process of mineralization.

5. The formation of ore veins proceeded not only by filling the open hollows. The results of replacement of gabbroic pegmatites filling the same fracture systems and of ores formed during preceding stages are widely distributed in veins.

6. The stage development of a mineralization process, accompanied by replacement phenomena, contradicts the deeply rooted concept, reflected in the literature, that the Nittis-Kumuzh'ye veins were formed as a result of a single stage of the filling of open fractures by an "ore magma" (or of injection of an "ore magma"). It suggests rather discontinuous ore-making and a pulsating influx of ore solutions.

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Leningrad

Received March 7, 1958

# HYDROTHERMAL MINERALIZATION IN CONNECTION WITH TRAPROCK OF THE MIDDLE COURSE OF THE NIZHNYAYA TUNGUSKA[1]

by

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The area of the middle course of the Nizhnyaya Tunguska, east of settlement Tur, up to and including a tributary of Iritka River, is made up exclusively of traprock. Two thirds of the area in the east is made up of a tuffaceous formation with traprock intrusions; the western half is covered by traprock of a lava formation. Among other rocks, there are rare lower Paleozoic outcrops in the Iritka basin.

All evidence of hydrothermal mineralization in the area, is related to intrusive and extrusive traprock. No plausible evidence of mineralization connected with pyroclastic formations, such as diagenetic processes, has been observed. All evidence of mineralization in tuffs has been found to be related to adjacent traprock intrusions.

The two lines of development of hydrothermal mineralization (post-intrusive and post-extrusive) differ in the manner of their manifestation and will be considered separately.

The post-intrusive mineralization, developing regressively from high- to low-temperature formations, has a clean-cut genetic relationship with the intrusions of the region.

The intrusions are represented by four morphologic types, spatially associated with definite stratigraphic units. Among rocks of the lower member of the tuffaceous formation, developed in the Iritka basin, small and extremely irregular intrusions (irregular bodies with apophyses, veins, and thin dikes) of fine-grained dolerite and dolerite porphyrite (tuffaceous sub-volcanic facies) occur. Large sill-like intrusions forming trough-like bodies are associated with the middle member of the tuffaceous formation, developed along the Nizhnyaya Tunguska from the mouth of Amo River to the Nizhnyaya Kochechumo. They are made up of coarse-grained porphyritic olivine dolerite. Intrusions typical of "eruption vents" are developed in the upper tuffaceous member. They are small multiphase stocks, or irregular massifs with finger-like apophyses at their top, or dikes changing from seemingly bedded deposits of olivine to olivine-free dolerite and basalt (extrusive subvolcanic facies). Locally these intrusions carry a number of tuffaceous xenoliths.

The fourth type of intrusion, represented by thick dikes, occurs in the area of development of the lava formation and of the upper tuffaceous member. Dikes are made up of coarse-grained olivine dolerite and are marked by their intensive contact metamorphic effect on the enclosing rocks.

Petrographically, intrusive traprocks of this area are differentiated into three groups: 1) normal dolerite and basalt of morphologic types one and three; 2) the Amok type of porphyritic anorthite diabase associated, according to V.S. Sobolev [12], with morphologic type two; 3) the Kiryamkin type of olivine dolerite which forms lava-cutting dikes.

Without pausing for a description of autometamorphic deposits appearing as secondary alterations in rock-forming trap minerals, a definite genetic series of hydrothermal formations connected with the intrusive magma can be set up (see table, next page).

The highest temperature stage of this process is expressed in the pyroxene-magnetite-apatite-zeolite formation. It occurs in veinlets in vertical joint surfaces; less commonly in vein-like pockets associated with intersections of vertical and inclined joint planes in the intrusive body itself.

The paragenetic association of minerals includes monoclinic pyroxene corresponding in composition to salite (intermediate member in the diopside-hedenbergite series) — (Ca Mg) (Mg $Fe^{2+}$) $Si_2O_6$; titanous magnetite containing 2 to 12.3% $TiO_2$ and a constant admixture of $V_2O_5$, of about 0.40%; apatite, (Ca, Sr)$_5P_3O_{12}$ (F, Cl, OH) carrying at times up to 2.13%

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[1] Gidrotermal'naya mineralizatsiya v svyazi s trappami srednego techeniya r. Nizhney Tunguski.

| Mineralization type (stage) | Mineral formations | Localization |
|---|---|---|
| High-temperature pneumatolytic-hydrothermal | a) Pyroxene-magnetite-apatite-thomasite<br>b) Contact-metasomatic-pyroxene-magnetite-apatite-zeolite. | Joints in intrusions<br>Enclosing rocks in immediate proximity to intrusion |
| Intermediate-temperature hydrothermal | Quartz-barite-sulfide-calcite | Enclosing rocks near intrusion |
| Low-temperature paleo-fumarole | a) Paleo-fumarole phase: garnet-vesuvianite-diopside formation<br>b) Paleo-mofette calcite-zeolite formation | Enclosing rocks, comparatively distant from intrusion |

rare earths [3]; and finally thomasite $(Ca, Na_2)Al_2Si_2O_8 \cdot 2H_2O$ with up to 0.40% SrO. A very small amount of sphene is almost always present. Spectrographic analysis reveals constant contamination of all minerals by Mn. Ga, Cu, Ti, V, Co, Ni, Cr, and Sr, with pyroxene and magnetite in places showing thousandths of a percent of Zr, Be, Sc, Mo, and Pb; rare earths are present in apatite (La, Ce, Nd).

The extent of development of this formation is very small, being only of mineralogic value. Its association with joint surfaces leads to the belief that their sources were hydrothermal differentiates of the trap magma, enriched by volatile components, also the occluded vapors and gases which surged into the nascent joint surfaces as the intrusive body cooled off.

The intermediate temperature stage is associated with the quartz-barite-sulfide-calcite formation. Here belong the quartz-barite-sulfide, quartz-calcite-sulfide, quartz-sulfide (polymetal), and quartz-hydrobiotite veinlets in tuffaceous rocks in the immediate proximity of traprock intrusions. Such veinlets commonly contain amorphous or crystalline mineral bitumens (asphaltite, evankite; [14]). Sulfides are represented chiefly by chalcopyrite and pyrite, less commonly by galena and sphalerite. We associate with the same stage (and formation) dispersions of pyrrhotite, pyrite, and arsenopyrite in endocontact parts of some intrusions.

The low-temperature stage represents the paleo-fumarole and paleo-mofette types of mineralization.

Only the surface evidence of fumarole phenomena has been observed in present volcanic provinces where the activity is connected with the cooling off of deeper intrusive bodies. Similar phenomena undoubtedly took place in paleo-volcanic provinces, namely on the Siberian platform, in the area of trap volcanism. They were the same hot emanations (vapors and gases) from cooling trap intrusions, which proceeded along fractures toward the surface and reacted vigorously with rocks along their way. We observe the traces of these fumaroles and mofettes in veinlets of hydrothermal minerals and in altered tuffaceous zones. Deep cuts in the valley system of the area affords an opportunity for a vertical tracing of paleo-fumarolic phenomena and the zonation in their distribution with a partial superposition of low-temperature formations over high-temperature ones.

The highest temperature phase is represented by garnet-vesuvianite and garnet-pyroxene skarn-like formations. Their exposures have been noted only along the Yado (Iritka River), in two localities — 400 meters and 10 kilometers from the mouth [11, 15].

In both instances, the "skarning" came about as a result of action of hot gases under high pressure, surging along fractures which were opening along the contacts of tuff with small earlier dikes of diabase porphyrite. The "skarning" fluids reacted with both the enclosing tuff and the diabase, to form garnet (grossularite), diopside, vesuvianite, and epidote. Spectrographic analysis of the altered rocks and minerals (garnet, vesuvianite) reveals the presence of Mn, Ti, V, Zn, Co, Ni, Zr, Cr, Sr, Ba.

At a final stage, the skarns were affected by calcite-sulfide (chalcopyrite) and chalcedony mineralizations (in the paleo-moffete phase) determined by the chemical activity of $CO_2$, $H_2S$, and $H_2O$. Spectrographic analysis of chalcopyrite shows that Cu and Fe are accompanied by Pb, Mn, and Ag.

The low-temperature paleo-mofette phase is more widely developed and is represented by zeolite-calcite veinlets with a sulfide

dispersion; these veinlets follow the joint planes in tuffs or the vertical fractured zones. In every instance, the adjacent tuffaceous rocks have undergone intensive zeolitization and carbonatization ("lighter-colored zones"). Mineralization in zones of shattering and brecciation of tuffaceous rocks is associated with the same phase.

Paragenetic mineral associations in these formations are fairly poor and monotonous; there are only three of them: 1) calcium-sodium zeolites (lomontite, heulandite, stilbite) — coarsely crystalline calcite; 2) finely crystalline calcite — sulfides (pyrite, chalcopyrite), coarsely crystalline calcite — calcium-sodium zeolites; 3) finely crystalline calcite — sulfides (pyrite, marcasite), coarsely-crystalline calcite — analcite, zeolites (natrolite, mordenite). The last two usually are accompanied in the zones of oxidation of sulfides by hydroxides of iron, jarosite, and gypsum.

Coarsely-crystalline calcite of terminal generations is an excellent optical raw material. Its depsoits, especially in the shattering zones of tuffs, are of great value.

Analyses of mineral associations and the chemical composition of individual minerals reveals the evolution of hydrothermal differentiates of the intrusive phase of traprocks in the area under study. At the outset, the residual differentiates were formed in the pneumatolytic phase with heavy volatile elements. A possible pneumatolytic-hydrothermal stage temperature, judging from the $TiO_2$ content in magnetite, was 400 to 800°C [4]; its terminal temperature of formation (thomasite) may have been 150 to 200°C.

The intermediate-temperature hydrothermal solutions probably were acid and contained Ba Sr, Si, Fe, Cu, Pb, Zn, Ag, and anions $S^{-2}$, $SO_3^{-2}$, $CO_3^{-2}$, and $H_2O$. In their penetration of tuffaceous rocks, these hydrogen sulfide solutions, enriched in heavy elements, encountered the air oxygen in ground water and reacted to form sulfates (barite) and sulfides. According to A.G. Betekhtin [2], such solutions, at a temperature of 350 to 400°C, are optimum for deposition of sulfides.

The formation of mineral bitumens which completed this stage took place as a result of complex chemical reactions of distilling organic matter from tuff in the course of contact-catalytic (heavy metals) processes, under low-temperature hydrothermal conditions. Similar phenomena are described by T.M. Maleyeva, from the Trans-Carpathia [9].

An analysis of the composition of minerals in the low-temperature stage shows that they consist of elements typical of traprocks, particularly of tuff. The added elements are Ca, Fe, Cu, $CO_2$, $H_2S$, $H_2O$, also Sr, Ba, Ti, and other inconspicuous elements revealed only by spectrographic analysis. Slightly acid solutions rapidly became alkaline, at early stages of sulfide formation, in a chemical reaction with volcanic material of tuff. The solutions leached Ca and alkalies (Na) out of the enclosing rocks, partly depositing Ca-Na-zeolites there, partly carrying them out to the open fractures and zones of shattering. The maximum temperature of all these formations probably was about 350 to 200°C; the minimum, as determined from the homogenization of liquid inclusions in the latest coarsely crystalline transparent calcite (Iceland spar), was 40 to 45°C (according to Ye. Ya. Kiyevlenko).

Contact-metamorphic phenomena related to traprock intrusions in the tuffaceous rock areas are extremely poorly developed. Tuffaceous rocks in exocontacts are turned to hornfels of a pyroxene-plagioclase composition. New mineral deposits are present only in the immediate contact zone, 3 to 5 centimeters thick. This zone is marked by a tubular-vuggy structure brought about by the presence of tubular hollows, 2 to 3 millimeters in diameter. Going toward the outer contact, these tubes are oriented normal to the contact boundary; going inside, they become parallel to the contact and disappear gradually. Isolated microscopic crystals of sphene and epidote have been observed along the tubular hollows. This scarcity of contact mineral deposits is explained not so much by a similarity in the chemical composition of the intrusive and the intruded rocks as by the fact that igneous bodies which sent forth the intrusions had been impoverished in volatile components — these main agents in contact-metamorphic processes — during a previous phase of volcanism.

The post-lava intrusions of the Kiryamkin type traprock had a different effect on enclosing rocks, in both tuff and lava. This effect was especially strong on lava, especially in lava flows in cliffs 55 and 73 kilometers above Tur settlement. Over a distance of 200 to 300 meters from the contact, the lavas have been fully altered to an albite-amphibolite rock with much sphene and apatite. In addition, a secondary amygdaloidal texture has been developed throughout the lava. The amygdules are either partly or fully filled by sphene crystals carrying 0.22% ZrO, apatite (without rare earths), diopside, magnetite, chalcopyrite, and zeolite (possibly thomsonite). Malachite has been observed in one place.

Contact alterations in lava flows, at dikes which cut them, are very interesting and novel phenomena in the Siberian platform according

to the literature on hand. We hope to obtain more detail on this subject. For the time being, we only note that both the altered contact rocks and the new mineral deposits are characterized by the same scarce elements and petrogeny typical of traprock; there was only a reshuffling of chemical compounds at high temperatures, in the presence of such chemically active volatile components as F, Cl, $CO_2$, $H_2O$, and $H_2S$. An analysis of addition and leaching of components in the course of a contact-metasomatic process shows a predominance of leaching. It has been determined that a considerable amount of CaO and $SiO_2$ is liberated in the albitization and amphibolization of extrusive diabases, with a reduction in the rock volume and with formation of a secondary amygdaloidal texture. The excess CaO and $SiO_2$, carried out by hydrothermal solutions, was fixed in surrounding rocks and in the lava sheets, as a superimposed silica-calcite vein mineralization.

The post-lava hydrothermal mineralization is marked by features of its occurrence and mineral composition, somewhat different than those of the above-described formations. Mineralization is very widely developed in lava sheets of the middle course of the Nizhnyaya Tunguska (the Tur settlement area). The visible thickness of the lavas here is 250 to 300 meters.

Massive and pillow lavas have been identified. The first are made up of massive basalt with an amygdaloidal texture at the top and the bottom. The amygdules are best developed at the top, where the density of such bodies, with an average diameter of 0.3 to 1.0 centimeter, is up to 50 to 80 per 10 $cm^2$. The thickness of individual sheets ranges from 3 to 30 meters. The upper amygdaloidal zone constitutes usually one-third of the sheet.

As a rule, a thin tempered crust, not over 10 centimeters thick, is present at the base of lava flows. Most lava sheets lie directly upon each other, making it impossible to observe their upper surfaces. However, when a lava sheet is overlain by a tuffaceous layer, typical rope-like relief is present in places on the surface. Contacts between the flows, as seen in exposures along the Nizhnyaya Tunguska, usually are extremely uneven, with tongue-like offshoots from the top of the lower flows into the base of the upper ones. Such segments are marked by very strong mineralization, often being made up of clinker rock. Such contacts between lava beds suggest short time intervals between the flows. The lower bed did not have the time to cool off, even at the surface, before it was overrun by another flow which dragged along some of the underlying material.

In their structure and origin, the pillow lavas were formed in a fresh-water environment [6], they are almost completely lacking in albitized rocks.

All lavas have a uniform chemical composition close to the universal plato-basalt of R. Daly. Petrographically, the lava flows differ only in their structural features. A.P. Lebedev indentifies the following varieties [7]: olivine and iddingsite basalt, amygdaloidal (mandelstein) basalt, plagiobasalt, dolerite and dolerite porphyrite, and tholeiite diabases. Rocks of the first and the last groups are best developed.

All manifestations of mineralization in the lava are believed to be of a low-temperature hydrothermal stage; we can differentiate only independent morphologic and genetic types. The order of formation of minerals of each type, together with their chemistry, will make it possible to reconstruct the conditions of formation of the hydrothermal complex of minerals.

The most widely developed is the amygdaloidal type of mineralization, affecting massive lava sheets (trizonal). It is represented by accumulations of hydrothermal minerals in amygdules having sharp contacts with the enclosing rock; the host rock is slightly crystallized about the amygdules, to form a tempered crust fractions of a millimeter thick. The observation data suggest that the filling of cavities occurred in the already hardened rock [7].

Vertically, the mineral composition of amygdules in a lava sequence changed altogether throughout the entire thickness. As early as 1945, G.G. Moor [10] proposed its use in correlating individual horizons of a lava sequence. Later on, K.G. Akimova [1], while differentiating the lavas of the Siberian platform into four stratigraphic members, recognized a different mineral composition for amygdules in different members. In the lower two members, amygdules are filled chiefly with quartz, chalcedony, and calcite; in the third — with zeolites and aragonite; and in the upper — with zeolites, quartz, and calcite. It the future, these data may be helpful in detailed differentiation of lava magmas.

The filling of vesicles in the lava took a long time in the course of diagenesis. All recent vesicular lavas, as old as lower Quaternary, have their vesicles unmineralized, as yet. In the cooling of lava flows, gases and vapors in the cavities, and occluded in the entire body of rock, passed — not without help from surface water — to hot, strongly mineralized (hydrothermal) solutions. Seepage of these solutions through amygdaloidal zones

has led to the gradual formation of an entire complex of hydrothermal minerals.

Judging from mineral associations, the composition of hydrothermal solutions in the Nizhnyaya Tunguska lavas was fairly monotonous. They carried Ca, Na, Al, Si, Fe, i.e., the principal petrogenic elements of the surrounding rocks as well as $CO_2$ and $H_2O$. Chemical study by A.V. Skropyshev [14] of gaseous and liquid inclusions in Iceland spar from lavas shows that the mineral-forming solutions were very concentrated (368 g/liter) and carried dissolved salts of $Na_2SiO_3$, NaCl, KCl, $AlCl_3$, $CaCl_2$, $CaSO_4$ and $Ca(HCO_3)_2$. Another clue to the composition of solutions in basic lavas is given by findings from liquid inclusions in amygdules in some Japanese basalts, where they are located next to those filled with liquid natrolite, montmorillonite, and calcite. The liquid inclusions are composed of concentrated solutions of Ca-Na chlorides and sulfates [18]. The formation temperature for the amygduloidal minerals probably was not over 100°C. The pocket type mineralization, closely related to lavas of spherical structure, is not so well developed in the lava sequence but is more diversified in mineral composition. Here, the accumulations of hydrothermal minerals are associated with the inter-pillow rock where they cement the fragments of volcanic glass and form sharply wedging out veinlets and pockets. The latter are formed chiefly in the space between several pillows and reach 1 to 1.5 meters in diameter.

The mineral association in pillow lavas is fairly diversified, although limited on the whole to hydrous silicates of Ca, Ca-Fe, Ca-Na, i.e., gyrolite [5], pectolite, and a calcium ferruginous chlorite-like mineral; aluminum silicates from the analcite, apophyllite, and prehnite groups; a group of zeolites, prominent among which are mordenite, heulandite, lomontite, stilbite, natrolite, thomsonite; calcite, aragonite, and varieties of silica; and a group of hydromicaceous minerals. Without pausing for the enumeration of typical paragenetic associations, a general regularity in the order of crystallization of minerals may be mentioned. First to be formed are calcium-ferrous silicates or siliceous compounds, followed by potassium-, sodium-, and sodium-potassium aluminum silicates; the latter gradually become more calcitic; and the process culminates in the formation of calcite. Such is the general course of a process which brings about the more complex mineral relationships.

The formation of such an association was promoted by the mandatory presence of outside water, in the formation of pillow lavas. The contact of water (fresh water in this instance) by incandescent bodies of lava has led to the formation of chemically active water vapors and hot solutions, which dissolved the volcanic dust and absorbed all gaseous emanations. The solutions were enriched in calcium, alkalies, silica, alumina, and iron in the initial stages; the volatile components, other than carbon dioxide, carried a comparatively large amount of fluorine which then entered the crystal lattice of apophyllites, and boron which entered datolite. Present in solutions also were elements determined by the spectrographic analyses of minerals: Sr, Mn, Ga, Cu, Ti, Sn, V, and Mo.

The probable maximum temperature of strongly alkaline hydrothermal solutions, according to experimental data of hydrothermal synthesis of hydrous silicates and aluminum silicates [17, 19], was approximately 250 to 300°C. The minimum temperature, corresponding to the temperature of formation of coarse-grained transparent calcite in the pockets, was 40 to 60°C, judging from homogenization temperature for liquid inclusions in the calcite (data of Ye. Ya. Kiyevlenko).

The formation of the entire pocket-type hydrothermal complex culminated in the formation of minerals from the ferromagnesian hydromica group. Fine-scalled aggregates of hydromicaceous minerals filled the empty hollows in pockets and replaced the apophyllite, heulandite, and stilbite, in places prior to the formation of complete pseudoporphs. This stage of the process corresponded to a change in physical chemical conditions, specifically to the substitution of acid for alkali solutions. The formation of quartz pseudomorphs on apophyllite, too, probably belongs to this stage.

The pocket type of hydrothermal mineralization in lavas is of great interest because of its association with deposits of Iceland spar, of low quality, to be sure.

Finally, we were able to identify another type of mineralization in the lavas — the superimposed vein type. This type is associated with lava flows, in the vicinity of post-lava dikes which cut them in the most weakened zones of mandelstein and pillow lavas. This mineralization is marked by an abundance of bedding and gently dipping veins of the following composition (in the order of precipitation): opal, chalcedony, finely-crystalline quartz, chalcopyrite, amethyst, calcite. Thus, the initial solutions were enriched in silica and calcium; they also carried Fe, Cu, $S^{-2}$, and $CO_2$. The solution temperature, at the time of crystallization of amethyst (intermediate-temperature stage), was 190 to 200°, judging from the temperature of it cracking up in slow heating.

In the same area, east of Tur, along the

Nizhnyaya Tunguska, the superimposed vein type of mineralization is widely developed in a lava member between the 55th and 73rd kilometers above Tur. The presence of veins elsewhere is a good reason for prospecting there for post-lava intrusive bodies.

All hydrothermal derivatives of both the intrusive and extrusive series are characterized by geochemical similarity. In all instances, the main mineral-forming elements are Ca, Na, Al, Si, Fe, Mg, i.e., these are the principal petrogenic elements of a traprock magma. The role of Mg in hydrothermal elements is extremely small; it appears only in minerals of the highest-temperature deposits (pyroxenes) and among the latest ones (hydromicas). The distribution of alkalies in hydrothermal deposits is similar to that in traprock, and is characterized by the dominance of sodium over potassium. The constant presence of admixtures of Ti, V, Cr, Co, Ni, Mo, Sc, and Ga in hydrothermal minerals, with a relatively greater abundance in intrusive hydrothermal differentiates than in the extrusive ones is also typical. Only the intrusive hydrothermal bodies are characterized by the presence of Zr, TR, and the polymetal group elements and their accompanying S and possibly As.

Sr and Ba are present in varying amounts in all hydrothermal minerals, from high-temperature intrusives (pyroxene, apatite, thomsonite) to low-temperature zeolites typical of extrusive types of mineralization (heulandite, lomontite), which confirm the typical affinity of these elements for traprock and contradicts the concept of their origin by assimilation, like that of Zr [8].

An opinion formerly prevailed that only such volatile components as $CO_2$ and $H_2O$ were associated with traprock magma. The presence of apatite containing F, Cl, and OH in intrusive hydrothermal deposits, and of F-carrying apophyllite in the extrusive ones, along with the presence of datolite, broadens this concept. The traprock magma carried enough F, Cl, P, B, and S; although it is possible that a considerable portion of these volatiles escaped into the atmosphere, because the traprock bodies were formed under near-surface and surface conditions.

Summing up what has been said, we believe that the geochemical similarity of all hydrothermal formations of the area under study is due to the fact that they all are related to a single traprock magma, while their mineral diversity has been caused only by different physical chemical conditions of formation.

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Received December 2, 1958

# GABBROIC PEGMATITE IN SINYAYA MOUNTAIN PYROXENITE, THE MIDDLE URALS[1]

by

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Rare gabbroic pegmatite in basic and ultrabasic rocks is described, with information on its geologic position, structural features, composition, and origin.

* * * * *

## THE OCCURRENCE, FORM, AND STRUCTURE OF PEGMATITE BODIES

Among the descriptions of gabbro and peridotite rocks, in the vast geologic literature on the Urals, there are frequent references to basic pegmatites. Most students call these formations, gabbroic pegmatites.[2]

In 1952, we mapped for the first time an entire field of gabbroic pegmatite development within the Sinyaya Mountain pyroxenite massif (Fig. 1). Pegmatite bodies are concentrated mostly on the eastern slope, in the hanging wall of the intrusion. Here, pyroxenite carries an abundant dispersion of titanomagnetite, along with isolated veins of ore mineral.

Pegmatites are located mostly in pyroxenite and hornblendite. Gabbro, in direct contact with ultrabasic rocks, carries only isolated pegmatoid bodies.

In their occurrence, form, and time of origin, pegmatites are divided into schlieren (syngenetic) and vein (epigenetic) types. Among approximately one hundred pegmatite bodies we have studied, most are veins, especially in hornblendite, while the schlieren are numerous in pyroxenite.

Gabbroic pegmatites are coarsely to gigantically crystalline formations, composed chiefly of plagioclase and hornblende, the latter developed autometasomatically on pyroxene. Titanomagnetite is of considerable importance.

Pegmatites of the same mineral composition differ in the qualitative ratios of their dark components and plagioclase, which results in melanocratic, mesocratic, and leucocratic varieties. Mesocratic pegmatites predominate in both the schlieren and vein types.

The schlieren pegmatites crystallized at the site of differentiation of the pegmatite melt from the mother rock. They are characterized by a close spatial relation to pyroxenite, occurring in all of the varieties of pyroxenite (fine-grained, coarse-grained, banded) but mostly in the pegmatoid feldspar-hornblendic ones with which they form gradual transitions.

The form and dimensions of schlieren pegmatites are variable, with lentils (0.3 x 0.5 meter), pockets (0.2 x 0.3 meter) and veins (0.3 x 0.2 meter) being the most typical. A beaded structure is occasionally observed, with alternating bulges and thin constrictions. Such bodies often send off thin apophyses of plagioclase in all directions.

The vein-like bodies are elongated submeridionally, parallel to the general strike of enclosing rocks and to their banding. Sharp discordance is common, however, such as that of a vein-like body of leucocratic pegmatite on the south slope of Gorelaya Gorka. It is located in pyroxenite enriched with plagioclase along subparallel planes. The banding is pyroxenite, striking northeast and dipping southeast at 70 to 80°, is cut latitudinally by pegmatite.

The schlieren pegmatites in pyroxenite and hornblendite are older than the gabbroic pegmatite veins. In the same locality, in the area of Gorelaya Gorka, pyroxenites carry a small lenticular body of pegmatite (without

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[1] Gabbro-pegmatity v piroksenitakh gory Siney na srednem Urale.

[2] We have kept this term, common in geologic literature.

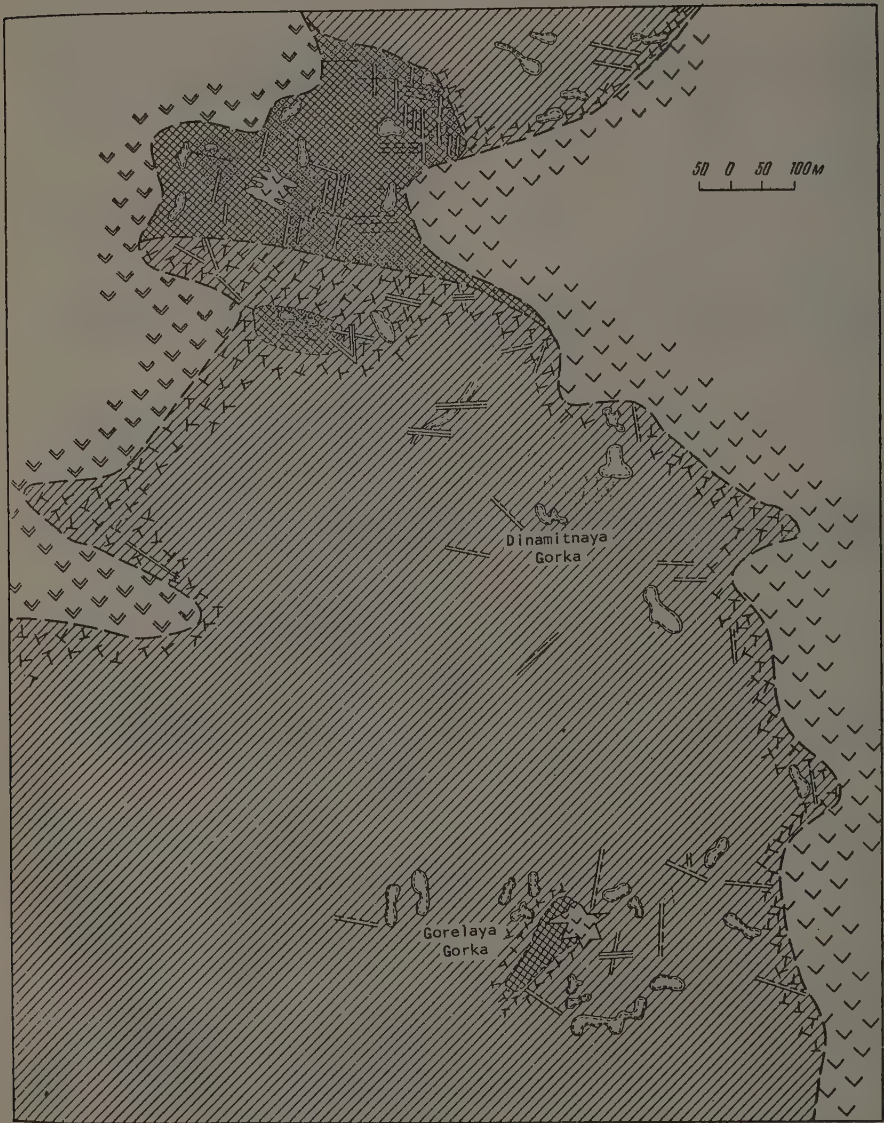


FIGURE 1. Distribution of pegmatite in pyroxenite and hornblendite.

1 -- Pyroxenite; 2 -- amphibolized pyroxenite; 3 -- hornblendite; 4 -- feldspathic hornblende rocks; 5 -- hornblende gabbro; 6 -- pyroxene-hornblende gabbro; 7 -- schlieren pegmatite; 8 -- simple veins; 9 -- zoned veins; 10 -- aplite veins.

titanomagnetite) but by a pegmatite vein with solitary grains of the ore mineral.

The principal minerals are distributed evenly in pegmatite, on the whole, although there are instances of a sharp differentiation of plagioclase in the dark component. For example, in one of the schlieren bodies of feldspathic pyroxenite (over 2 meters long, 50 to 70 centimeters thick in bulges and 10 to 20 centimeters thick in constrictions),

Regular crystals of titanomagnetite are commonly grouped at the pegmatite-pyroxenite boundary to form a discontinuous fringe, with a sort of zoned structure as a result.

The vein pegmatites were formed as a result of displacement and crystallization of pegmatite solution along fractures in the mother rock. The vein bodies are closely related in space to the schlieren. The enclosing rocks are the same pyroxenite and horn-

FIGURE 2. I -- vein-like body of gabbroic pegmatite in feldspathic pyroxenite; II -- vein of leucocratic pegmatite with titanomagnetite (black). The enclosing rock is feldspathic pyroxenite. 3/4 natural size.

there is an alternation of feldspathic and pyroxene-hornblende segments (Fig. 2, I).

In some pegmatite bodies (most commonly in pockets), pyroxene and hornblende are accumulated along the pegmatite boundary with the enclosing pyroxenite, with practically plagioclase alone left in the central part.

blendite with a fairly well expressed primary banding.

Standing out locally among the greenish-gray pyroxenite are bands enriched in plagioclase, with hornblende and coarse nodules of titanomagnetite located between them. The trend of these bands is generally almost

meridional. They are cut by a series of parallel veinlets of leucocratic pegmatite where titanomagnetite is almost the only dark mineral (Fig. 2, II).

The pegmatite veins fill up fractures, trending chiefly meridionally and latitudinally, with sharp contacts; they frequently cut the primary banding of pyroxenite. The effect of vein pegmatites on the emplacing rocks was very slight, leaving practically no appreciable alteration along the contacts. The pegmatites are represented by both simple and zoned veins.

Simple pegmatite veins generally trend meridionally, dipping at angles of 40° to 70°. Their thickness is usually small, about several tens of centimeters, with only a few veins of over one meter thick. Most veins, especially in pyroxenite, are marked by rectilinear outlines and a consistent thickness. Veins in hornblendites commonly are made up of numerous thin apophyses, and their thickness varies along the strike.

Most simple veins show a typical pegmatitic, even coarse-grained texture, with occasional dark and plagioclase bands.

Zoned veins, unlike the simple ones, are more commonly associated with the longitudinal system of fractures, with steep dips. They are marked by rectilinear outlines and by a comparatively great thickness (up to 1.5 meters). They differ in the degree of zonation, from simple to complex. The most complex zonation, is present in the thickest (1.5 meters) unconformable vein in hornblendite, which we have traced latitudinally for tens of meters. The central and the wall portions, each 10 to 20 centimeters wide, are represented by an evenly crystalline mesocratic pegmatite. Located symmetrically between them are the widest (45 to 50 centimeters) zones where long and thick subparallel hornblende crystals are oriented across the vein. Plagioclase in the interstices between them has the same orientation. At about the middle of it, each zone appears to be cut in two halves, normal to the hornblende orientation, by very narrow (5 to 8 centimeters) bands of a mesocratic, evenly crystalline pegmatite. All segments of the zoned pegmatite carry an abundant dispersion of titanomagnetite whose grains are almost always associated with plagioclase.

It has been frequently observed that zoned veins are of a later origin than the simple ones, and that the latter cut the schlieren pegmatites. A simple vein cut by a zoned one (Fig. 3) is shown in one of the large outcrops of medium-grained hornblendite with a large number of pegmatite veins. Titanomagnetite in the simple vein is represented by isolated grains and nodules related to plagioclase; in the zoned vein, it is represented by fewer grains along the plagioclase-hornblende boundary. At the intersection, neither the composition nor the structure of pegmatite are altered. In the same locality but in coarse-grained hornblendite, a series of subparallel simple pegmatite veins with a sparse titanomagnetite dispersion is seen to cut a lense-like body of mesocratic pegmatite.

Of interest is the relationship of the schlieren and vein pegmatites to other vein rocks in Sinyaya Mountain.

Gabbroid veins are fairly common in the center of the hornblendite area, near its boundary with gabbro. We have succeeded in finding a rare situation — a gabbro vein cutting simple pegmatite veins (Fig. 4). The vein gabbro carries a considerable amount of titanomagnetite, while the pegmatite, barren of ore minerals, is made up of strongly chloritic hornblende and pink plagioclase.

More common are aplite veins cutting the pegmatites. For example, medium-grained pyroxenite (with pegmatoid nodules) in the Gorelaya Gorka carry a conformable vein of leucocratic pegmatite, dipping east at 60° and consisting completely of plagioclase densely saturated with titanomagnetite. It is cut almost normally by a latitudinal vein of plagioclase, 0.15 meter thick. South of the hornblendite area, amphibolic pyroxenite also carries a fairly thick (1 meter) vein of mesocratic pegmatite, trending latitudinally and cut by a network of small younger veinlets of dioritic aplite, branching off a thick aplite vein.

## THE COMPOSITION OF GABBROIC PEGMATITE

The principal minerals of the Sinyaya Mountain pegmatites are pyroxene, hornblende, plagioclase, and titanomagnetite. Among the secondary minerals are spinel, sphene, and to a smaller extent, apatite, with occasional quartz. All minerals are more or less altered.

Pyroxene forms either irregular bodies or rare prismatic crystals, 10 to 15 centimeters long, 5 to 6 cm thick, greyish to brownish green, locally with a darker hornblende fringe. Its content is the greatest (4% to 10%) in melanocratic pegmatites approaching in their (pyroxene + amphibole) : plagioclase ratio of (85% to 90%) : (5% to 10%) to plagioclase pegmatoid pyroxenite. The microscope reveals the slight coloring of pyroxene and its distinct cleavage. Occasional (100) twinning has been observed.

Pyroxenite from pegmatite (2V = 57 to 60°;

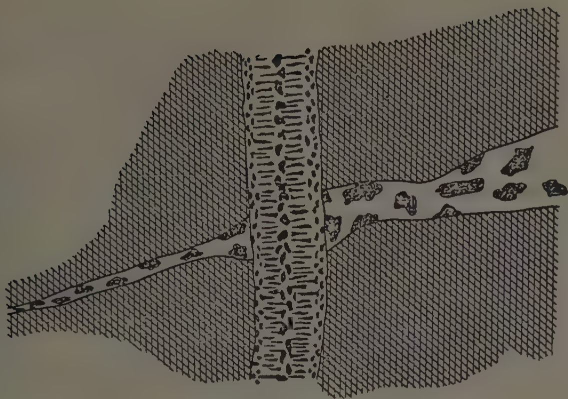

FIGURE 3. A zoned vein cutting a single pegatite vein. Enclosing rock is hornblende. Scale: 1:10.

$c\gamma$ = 35 to 39) and from the enclosing pyroxenite (2V = 60°; $c\gamma$ = 38) is fairly similar, both belonging to diopside and diopside-diallage with a variable content of the hedenbergite molecule. The iron content in pyroxene increases appreciably, going from pyroxenite ($\gamma$ = 1.707; $\alpha$ = 1.687) and melanocratic pegmatite ($\gamma$ = 1.705; $\alpha$ = 1.684) (up to 20% hedenbergite) to leucocratic pegmatite ($\gamma$ = 1.716; $\alpha$ = 1.691) (over 25%), where pyroxene approaches salite.

Nearly all thin sections show replacement of pyroxene by hornblende. As a rule, it starts at the periphery of the grains and proceeds inward. Unaltered pyroxene crystals still occur in pegmatite, in unaltered pyroxenite, although even here they are mostly fringed by hornblende; in pegmatites from amphibolic pyroxenite, pyroxene occurs only

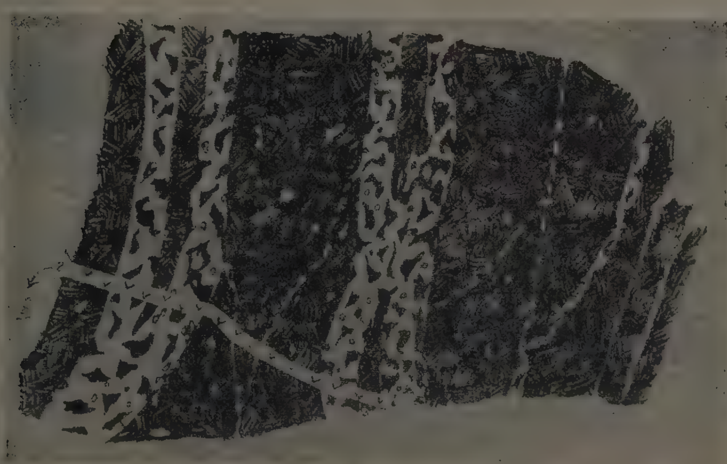

FIGURE 4. Ore gabbro vein cutting simple pegmatite veins. Enclosing rock is hornblendite. Scale, 1:30.

in small relicts; in pegmatites from hornblendite, it is fully replaced by hornblende.

Hornblende is the main component of these pegmatites, its content increasing toward the northern edge of the area under study; here, it fully replaces pyroxene in both pegmatites and the enclosing pyroxenite which changes either to hornblende pyroxenite or to hornblendite, depending on the degree of alteration. Schlieren pegmatites, carrying as they do more dark minerals in all of their varieties, correspond most closely to the composition of the enclosing rocks.

Hornblende forms coarse short prismatic (5 to 6 centimeters long) crystals in pegmatites of simple veins; and long, up to 10 to 15 centimeters, thin prismatic crystals in zoned veins. Present at times are well-defined hexagonal and octagonal cross-sections of large crystals (up to 6 or 8 centimeters). Unaltered hornblende is usually pitch black and strongly lustrous on cleavage planes. On the other hand, its chloritic crystals are dull, irregular in form, and greenish brown in color.

Hornblende occurs in the following forms: regular idiomorphic crystals, commonly prismatically twinned; in less perfect crystals, either elongated or more isometric, with uneven, indented edges; in fringes about pyroxene and magnetite; and in micropegmatite growths with pyroxene.

Hornblende enters all varieties of pegmatite. Systematic measurements of its refraction (Table 1) have shown that it belongs to a single type, which confirms the close kinship of all pegmatites to each other and to the enclosing pyroxenite and hornblendite.

There is little difference in the coloring of hornblende. Somewhat different are vein gabbric pegmatites which almost always exhibit bluish pleochroism along $\gamma$ for hornblende — apparently an evidence of higher alkalinity.[3]

A comparison of the chemical analyses data (Table 2) for hornblende from pegmatite in pyroxenite and hornblendite shows the similarity in composition. It appears that hornblende from the enclosing rocks themselves would be close to them, in their chemistry, as should be expected from the optical data. The data of chemical analysis for hornblende from the Kachkanar pyroxenite, which we have at our disposal, are similar in many respects to those for hornblende from the Sinyaya Mountain pegmatites. The difference is in a somewhat greater $TiO_2$ content, in the increase of ferric iron, and in the change in the FeO/MgO ratio, in the direction of increase in Mg content.

In pegmatites from pyroxenite in the central part of the area under study, hornblende is mostly fresh; in amphibolic pyroxenite (near-contact zone with gabbro), it is only slightly replaced by epidote and chlorite, along the crystal edges; in hornblendite of the northern segment, confined between gabbro bodies, hornblende was subject to vigorous processes of epidotization, zoisitization, and chloritization.

F. Yu. Levinson-Lessing, in his time, asked, on the subject of the origin of hornblende and of its relationship with pyroxene in the Sinyaya Mountain pyroxenites, "Are the pyroxene and hornblende simultaneous and independent precipitates from a magma or is one of them a product of the other?" His answer was that both alternatives are possible and in fact present. The second alternative is more probable for pegmatite.

Hornblende in different varieties of schlieren and vein pegmatite has a fairly consistent composition; also, it definitely replaces pyroxene. Consequently, there are reasons to believe that the pegmatite pyroxene was formed at the expense of pyroxene which had been precipitated at an early basic stage of the pegmatite crystallization culminating in the appearance of plagioclase. Subsequently, in those places where the pegmatite solution contained some volatiles, especially water, following the precipitation of minerals of the basic crystallization stage, pyroxene was replaced by hornblende; this process was less intense in the inner part of the pyroxenite intrusion, and more intense in its hanging wall. The volatile compounds are known to have been carried to the endocontact zones.

It is difficult to imagine the presence of primary hornblende in pegmatite. First, the results of its study suggest the existence of a single variety. Second, plagioclase in pegmatite is fully replaced by saussurite, while hornblende, if it is to be assumed as primary, has remained unaltered, for some reason. This incongruity disappears if we assume that the original composition of pegmatite was represented by pyroxene, plagioclase, and titanomagnetite, which then underwent processes of a comparatively high-temperature replacement. Pyroxene was replaced by hornblende; plagioclase was saussuritized; and leucoxene developed on titanomagnetite (ilmenite).

Plagioclase is very essential for leucocratic pegmatites in which it commonly makes up the

[3] Hornblende in the Sinyaya Mountain gabbroic pegmatites does not follow the relationship between pleochroism and refraction, demonstrated by V.F. Morkovkina.

Table 1

Refractive indices for hornblende[a]

| Pegmatite types | γ | | α | | Coloring along α | |
|---|---|---|---|---|---|---|
| | Schlieren | Vein | Schlieren | Vein | Schlieren pegmatite | Vein pegmatite |
| Leucocratic pyroxenite | 1.679 | 1.685 | 1.661 | 1.661 | Pale-green | Pale-green |
| Leucocratic hornblendite | 1.678 | 1.682 | 1.662 | 1.661 | Green | Blue-green |
| Mesocratic pyroxenite | 1.672 | 1.672 | 1.652 | 1.656 | Light-green | " |
| Mesocratic hornblendite | 1.678 | 1.678<br>1.680 | 1.662 | 1.660<br>1.662 | Brown-green | " |
| Melanocratic pyroxenite | 1.675 | 1.680 | 1.675 | 1.661 | Green | " |
| Melanocratic hornblendite | 1.678 | 1.680 | 1.662 | 1.662 | Brown-green | " |
| Pegmatoid pyroxenite | 1.679 | | 1.660 | | Light-green | |
| Pegmatoid blendite | 1.679 | | 1.661 | | Green | |

[a] Determined by the immersion method. Determination precision, ±0.003.

entire veins; its content is the least (5% to 10%) in melanocratic pegmatites approaching pegmatoid feldspathic pyroxenite and hornblendite.

In the Sinyaya Mountain pegmatoids, plagioclase is generally evenly distributed, with its monomineral segments in places isolated from the schlieren ones, while bands of it are present in vein pegmatite. Being precipitated after dark minerals, it fills up interstices between them (Fig. 5) and acquires a peculiar form in zoned veins where it is found between the long prismatic hornblende crystals, with the same orientation normal to vein walls.

Most pegmatite bodies, especially the leucocratic varieties, are marked by an association of plagioclase with titanomagnetite which, being located within its crystals, stands out in relief, on the weathered surface.

Plagioclase crystallized somewhat later than pyroxene. This is suggested by the penetration of plagioclase into the pyroxene crystals, also by their corrosion by plagioclase.

Different types of plagioclase in pegmatites were replaced to a different extent. Microscopically, this is reflected in their color change. In the central part of our area,

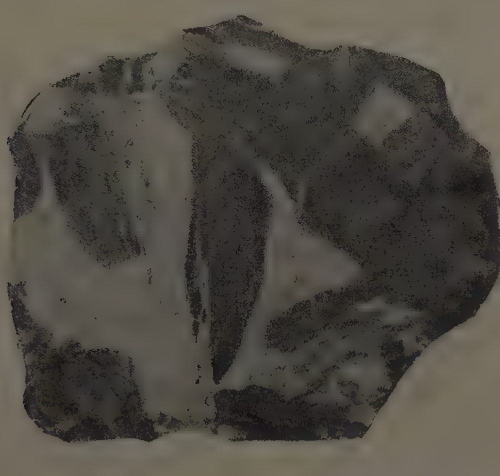

FIGURE 5. Differentiation of plagioclase in schlieren pegmatite. 9/10 natural size.

Table 2

Chemical Analyses of Principal Minerals in Gabbric Pegmatite

| Anal. No. | Minerals and the sample location | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | Hornblende | | | | | | | | | |
| I | Mesocratic pegmatite vein in pyroxenite | 39,96 | 1,02 | 15,05 | 3,23 | 8,11 | 0,05 | 13,71 | 12,06 | 1,13 |
| II | Mesocratic pegmatite vein in hornblendite | 39,88 | 1,27 | 15,05 | 3,48 | 8,87 | 0,07 | 13,38 | 12,12 | 1,07 |
| III | Pegmatoid body in gabbro of eastern zone | 39,76 | 1,27 | 15,38 | 3,28 | 3,30 | 0,10 | 13,54 | 12,22 | 1,22 |
| IV | Hornblende pyroxenite (Kachkanar Massif) | 40,10 | 1,68 | 14,97 | 4,52 | 6,62 | 0,09 | 15,10 | 12,40 | 1,54 |
| | Plagioclase | | | | | | | | | |
| I | Blue-gray saussuritic plagioclase from pegmatite in pyroxenite | 43,45 | trace | 31,57 | 0,73 | trace | 0,07 | 0,18 | 18,97 | 1,84 |
| II | Pink pelitic plagioclase from pegmatite in hornblendite | 41,76 | » | 33,26 | 0,68 | » | 0,06 | 0,12 | 16,24 | 2,01 |
| III | Yellow-green epidotic plagioclase from pegmatite bodies in gabbro | 39,31 | 0,02 | 30,29 | 4,74 | 0,27 | 0,09 | 0,26 | 21,56 | 0,67 |
| IV | Altered feldspar from plagioclase vein in the Sinyaya Mount. pyroxenite | 42,62 | — | 32,50 | 0,56 | — | — | 0,06 | 15,63 | 2,67 |
| V | Fresh plagioclase No. 70-95 from a large body in pyroxene-hornblende gabbro (Kytlym area) | 43,62 | 0,41 | 29,52 | 2,47 | 2,56 | 0,04 | 2,06 | 17,72 | 0,91 |
| VI | Plagioclase, fresh, No. 70-75, from a plagioclase inclusion in gabbro (Kumba Mountain) | 43,95 | none | 33,90 | 0,65 | not det. | not det. | 0,30 | 17,75 | 1,15 |
| | Titanomagnetite | | | | | | | | | |
| I | From mesocratic pegmatite in pyroxenite | — | 5,47 | — | 57,59 | 29,37 | — | — | — | — |
| II | From mesocratic pegmatite in hornblendite | — | 3,75 | — | 60,80 | 29,47 | — | — | — | — |
| III | From pegmatoid feldspar-hornblende pyroxenite | — | 5,59 | — | 56,91 | 29,46 | — | — | — | — |

plagioclase from pegmatite is uniformly blue-yellow to grayish blue; as shown under the microscope, this corresponds to the development of a saussurite aggregate which fully replaces the plagioclase. With the approach to the periphery, especially in the north and particularly in the area of hornblendite development, plagioclase in pegmatites appears to lost its luster. First, its color becomes spotty, blue-yellow-pink, then pale to bright plagioclase appears in an ever increasing amount. In thin sections, mottled plagioclase presents an alternation of saussuritic, epidotic, and pelitic segments.

Table 2, continued

| $K_2O$ | $H_2O^-$ | $H_2O^+$ | $CO_2$ | $P_2O_5$ | S | F | Cl | $Cr_2O_3$ | Ni | Co | Cu | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0,67 | 0,45 | 3,00 | 1,14 | present | present | none | trace | — | — | — | — | 99,52 | Author's material; B.M. Yeloyev, analyst; 1955 |
| 0,80 | 0,50 | 3,45 | 0,70 | » | » | » | » | — | — | — | — | 100,64 | |
| 0,75 | 0,55 | 3,59 | 0,44 | — | — | 0,04 | — | — | — | — | — | 100,44 | |
| 0,75 | — | — | — | 0,007 | 0,05 | — | — | 0,02 | trace | 0,03 | 0,01 | 97,89 | From material of K.D. Timokhov, 1953 |
| 0,49 | 0,05 | 2,24 | 0,40 | not found | trace | 0,06 | not found | — | — | — | — | 100,05 | Author's material; T.M. Mityushina, analyst; 1955 |
| 0,73 | 0,34 | 4,48 | 0,40 | » | » | 0,02 | little | — | — | — | — | 100,04 | |
| 0,12 | 0,08 | 2,28 | 0,30 | 0,12 | $SO_3$ 0,04 | 0,04 | » | — | — | — | — present after heating | 100,19 | From publication of F. Yu. Levinson-Lessing; 1909 |
| 1,34 | — | — | — | — | — | — | — | — | — $V_2O_5$ | — CaO | 5.63 CuO | 101,01 | Material of O.A. Vorob'yeva and N.V. Samoylova; O.P. Ostrogorskaya, analyst; 1953 |
| 0,15 | 0,11 | 0,28 | — | 0,08 | 0,01 | — | — | — | 0,09 | 0,04 | 0,005 | 100,07 | Material of Ye.V. Sveshnikova; O.N. Alekseyeva, analyst; 1953 |
| — | 0,13 | 1,62 | — | — | — | — | — | — | — $V_2O_5$ | — | — | 99,45 | |
| — | — | — | — | — | — | — | — | 0,06 | 0,82 | — | — | — | Author's material; O. Nikolayeva, analyst |
| — | — | — | — | — | — | — | — | not found | 0,88 | — | — | — | |
| — | — | — | — | — | — | — | — | » | 0,80 | — | — | — | |

NOTE: Comma represents decimal point.

All this suggests not only an intense development of the original saussurtization process but of the subsequently superimposed processes of epidotization and pelitization, as well.

Because plagioclase has been fully replaced, its optical study is difficult. Isolated measurements on the Fedorov table (in the symmetrical extinction zone) of those plagioclases where polysynthetic twins are barely discernible in a homogeneous saussurite matrix, suggest labradorite No. 58-60.

In determining the composition of plagioclase,

all attempts at isolating unaltered mineral were in vain. However, it was possible to analyse plagioclase affected by various replacement processes. Selected for this purpose was blue-gray saussuritic plagioclase from the most common mesocratic pegmatite of vein type, in pyroxenite (Analysis I); a pink pelitic plagioclase from a similar pegmatite in hornblendite (Analysis II); and a greenish yellow epidotic plagioclase from pegmatite in the eastern belt, isolated in gabbro (Analysis III). The results of a chemical analysis are given in Table 2.

The analysis has confirmed the presence of a complex assemblage of the replacement phenomena, expressed in definite ratios of individual oxides typical of a process. For instance, epidotization and zoisitization of plagioclase are distinct in Analysis III. The CaO content increases considerably (21.56%) as compared with saussuritized (18.97%) and pelitized (16.24%) plagioclase. The $Fe_2O_3$ content grows several times, accompanied by the appearance of ferrous iron. At the same time, the $SiO_2$ and $Al_2O_3$ content is appreciably reduced.

Saussuritic (Analysis I) and pelitic (Analysis II) plagioclases are closer to their composition because the alteration products are the same in both instances, being epidote, zoisite, and sericite. However, the predominance of pelitic material is reflected in the increase in the alumina and water content, and in the smaller proportion of calcium and silica. The increase in alkalies, especially in potassium, reflects an increased sericite content.

Titanomagnetite is the only ore mineral in these pegmatites.[4] Only a few isolated bodies do not carry it in dispersion. Such barren pegmatites constitute 5% to 10% of the entire body. On the whole, melanocratic pegmatites carry the least titanomagnetite, with its content increasing in mesocratic and especially in leucocratic varieties.

Titanomagnetite occurs most commonly in plagioclase crystals, less frequently on the plagioclase boundary with pyroxene and hornblende where it forms irregular xenomorphic bodies. In leucocratic pegmatites, where an ore mineral is the main dark component, it appears to cement the plagioclase. Present in titanomagnetite are inclusions of green spinel and growths of ilmenite.

Partial chemical analysis was applied to titanomagnetite from mesocratic pegmatite in pyroxenite and hornblendite, also from a feldspar-hornblende pyroxenite.

The data obtained indicate, first of all, the identical composition of titanomagnetite from pegmatite in pyroxenite (Table 2, Anal. I) and from pyroxenite itself (Anal. III). Of note is the analysis of ore mineral from pegmatite in hornblendite (Anal. II).

The analysed ore mineral from pegmatite, like the enclosing pyroxenite, belongs to titanium-poor and vanadium-carrying magnetites very typical of the so-called Kachkanar ore type represented in the Middle and Northern Urals by their dispersion in pyroxenite.

Titanomagnetite is precipitated in pegmatites after pyroxene. Its relationship with plagioclase suggests a partial coincidence of the precipitation periods from these two minerals, on one hand, and a later culmination of the crystallization of ore mineral, on the other. Some veins of mesocratic pegmatite display hornblende and plagioclase being cut by thin fractures filled with the ore mineral.

Titanomagnetite in pegmatite has been altered to a considerably smaller extent than the above-described minerals. Still, it can be seen in individual ore grains that hematite and leucoxene are being developed in fractures and along the ilmenite plates, in places so intensively that only the skeletal forms are left from magnetite grains. The most common non-ore mineral forming on titanomagnetite is chlorite, more rarely epidote and zoisite.

The Sinyaya Mountain pegmatites are very poor in accessory minerals. Only spinel accompanies them in pyroxenite; in hornblendite, it is joined by sphene and apatite.

Spinel (green) is mostly associated with titanomagnetite (leucocratic pegmatite in pyroxenite) in small grains. It is considerably less plentiful in pegmatite in hornblendite, where it is frequently accompanied by epidote.

Sphene and apatite are rare in pegmatites and have been observed only in varieties associated with hornblendite.

All principal minerals from pegmatites have been spectrographically analysed, with sphene alone among the accessories;[5] also the pegmatites themselves (including the pegmatoid bodies in gabbro) and the enclosing rocks: pyroxenite, hornblendite, and gabbro.

[4] Sulfides (pyrite and chalcopyrite) have been found only in isolated pegmatoid bodies in gabbro.

[5] As shown by the chemical analysis, sphene does not carry rare earths.

The results so obtained are monotonous, on the whole, with some details of interest. For example, chromium is present in gabbroic pegmatite in smaller amounts than in the enclosing pyroxenite and hornblendite. It is lacking pegmatoid bodies in gabbro and in the gabbro itself.

Copper has been found in very small amounts, in gabbroic pegmatite from pyroxenite and hornblendite; however, its amount is considerably greater in pegmatoid bodies in gabbro and in the gabbro itself.

Titanium is the most common added element in pegmatite and in the enclosing rocks. Its somewhat higher content in pegmatite from hornblendite apparently is due to the presence of accessory sphene; the enclosing rocks carry more chromium and vanadium than do the gabbroic pegmatite; scandium is altogether missing in the latter.

## THE ORIGIN OF GABBROIC PEGMATITE

It appears from the data cited that the main features of the genesis of gabbroic pegmatite in ultrabasic rocks of the Sinyaya Mountain are as follows:

1. Gabbroic pegmatites are concentrated in the hanging wall (eastern peripheral segment) of a pyroxenite intrusion, with chiefly schlieren bodies developed in pyroxenite, and vein bodies in hornblendite.

2. The spatial distribution of pegmatites was greatly affected by fracturing which determined their number and at times the form and structure.

In the deposit area, pegmatite veins chiefly follow two fracturing trends — submeridional and sub-latitudinal — which are the two main trends of the entire pyroxenite massif. It appears that the fractures were reopened several times, to form numerous zoned pegmatite veins along with the simple ones.

3. Pegmatites in both pyroxenite and hornblendite represent a genetically discrete group closely related to the enclosing mother rocks from which they differ by the presence of considerable plagioclase, by the large size of crystals, and by a peculiar (pegmatitic) texture.

The general features of the enclosing rocks and the pegmatites are as follows: a) the lack of near-contact alteration; b) the presence of coarse-grained pyroxenite carrying plagioclase; in places they take on a pegmatoid texture and locally change directly to pegmatite; 3) the presence of melanocratic pegmatite approaching the pegmatoid feldspar-hornblende pyroxenite, in their ratio of plagioclase to the dark fraction; and d) the principal minerals in both pegmatite and the enclosing rocks (pyroxene, hornblende, plagioclase, and titanomagnetite) have fairly stable optical and chemical properties and a very limited number of added elements.

4. Autometasomatic processes which occurred in a definite sequence were very active in the formation of gabbroic pegmatites.

The earliest high-temperature stage included the replacement of pyroxene by hornblende and of plagioclase by saussurite. This alteration followed directly a true pegmatitic stage of the primary minerals' crystallization (pyroxene and plagioclase).

A later and comparative low-temperature replacement stage was expressed in chloritization which affected, to a different extent, all the main minerals in pegmatite, with hornblende the most affected. This stage also witnessed a local (in the north only) pelitization of plagioclase.

The process of epidotization-zoisitization was initiated as early as the relatively high-temperature replacement stage, and persisted in the lower-temperature stages, thus occupying an intermediate position.

The enclosing rocks, especially in pegmatoid segments with plagioclase, exhibit the same replacement processes, and in the same order.

The sum of observations on the Sinyaya Mountain gabbroic pegmatites leads to the conclusion that they are derivatives of an ultrabasic magma and appeared at the culminating stage of the formation of this pyroxenite massif. The residual pegmatite solution, differing from the magma in its higher content of aluminum silicates and water, penetrated the hanging wall of the intrusion, at the place of a development of titanomagnetite mineralization. Therefore, the ore dispersion in pegmatite, especially high in the leucocratic variety, is not an accident.

The pegmatite process probably started off with the initiation of syngenetic pegmatoid feldspar-hornblende differentiates and continued with schlieren pegmatites — pocket, lenticular, vein-like — from the melanocratic through mesocratic to leucocratic varieties.

The vein-like bodies, as a rule, are distributed parallel to the internal structure of the massif, trending meridionally; however, some examples of discordance suggest a displacement and a separation of magmatic melt from the main body. Typical vein

pegmatites have also been observed, filling both the meridional and latitudinal fractures.

Along with gabbroic pegmatite, related in time of origin to ultrabasic rocks, there undoubtedly are gabbroic pegmatites formed from a gabbroid melt.

It appears that each major intrusive facies may be accompanied by pegmatites of its own. Of interest in this regard are our additional observations on pegmatoid bodies in gabbro which is in direct contact with the hanging wall of the Sinyaya Mountain pyroxenite intrusion. In composition, these bodies are reminiscent of pegmatites from pyroxenite, because they are made up chiefly of hornblende, close to them in composition (Table 2, Anal. IV), and of epidotic plagioclase (Table 2, Anal. III). At the same time, the lack in them of spinel in paragenetic association with titanomagnetite, and the presence of abundant dispersions of pyrite and chalcopyrite, reflect the fine differences in composition which are typical of the enclosing gabbro.

There are references in the literature to two groups of gabbroic pegmatites. On the basis of these rather scarce descriptions, the first group may be correlated with gabbroic pegmatites from the Sinyaya Mountain pyroxenite. These are pegmatites described by A.N. Zavaritskiy [2] and Ye.P. Moldovantsev [4] from the Polar and Northern Urals; they show everywhere a paragenetic association of titanomagnetite and spinel; sulfides of copper, quartz, and K-feldspar are absent; and the basic composition of plagioclase is typical.

According to F.F. Grout (1918), G.L. Padalka [6], N.A. Sirin [7], N.Z. Yevzikova [1], G.N. Staritsina [8], also N.P. Lupanova and Ye.V. Sveshnikova, there is another group of pegmatites, with which the pegmatoid bodies in the Sinyaya Mountain gabbro may be associated. Pegmatites of this group may carry a more acid plagioclase, along with K-feldspar and quartz, at times in a fine graphic intergrowth. Regardless of the composition of the feldspars, they always carry sulfides of copper and iron.

Gabbroic pegmatites as derivatives of an ultrabasic magma are considerably less common, and each new finding is of special interest.

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Received April 24, 1958

# NEW DATA ON LOWER CARBONIFEROUS STRATIGRAPHY AND LITHOLOGY OF TUVA[1]

by

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New data are cited for a more detailed differentiation and refinement of the composite stratigraphic scheme for the lower Carboniferous of Tuva.

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The literature dealing directly or indirectly with the stratigraphic differentiation of the pre-coal lower Carboniferous in Tuva is very limited. The earliest works on this subject are those of Z.A. Lebedeva who united Carboniferous deposits with the Devonian into a single "Beykem complex," Devonian-Carboniferous in age.

This "Beykem complex" was subdivided into the following five formations (reading upward): the Otokshil', the Ust'-Uyuk, the Shivilik, the Zvenyashchaya, and the Dzharik. According to present concepts, the two lower formations are Devonian; the two upper, lower Carboniferous; and the Shivilik is Devonian in its lower part and Carboniferous in the upper.

In 1936 a work of M.F. Neyburg [6] was published, dealing chiefly with the flora and stratigraphy of the Tuva coal measures, with some data on the pre-coal Carboniferous formations. From their plant remains, the latter were correlated with the lower Carboniferous Minusinsk formation from the Minusinsk trough. M.F. Neyburg also noted the great similarity in the lithology of lower Carboniferous deposits from these two provinces.

In 1951 the 1:1,000,000 geologic map of Tuva was published with a legend, both compiled by A.L. Dodin and G.A. Kudryavtsev [1]. Lower Carboniferous deposits are represented here by the Arguzun sequence[2] (formation) whose age was determined as $D_3 + C_1$.

The latest literature on Tuva geology [2, 5], that part of it dealing with the pre-coal Carboniferous, contains nothing which is not in the works of Z.A. Lebedeva. It does not mention the unpublished results of the last decade of work by the VSEGEI (All-Union Geological Institute) geologists (Ya. S. Zubrilin, A.M. Danilevich, N.N. Predtetchenskiy) and the geologists of the Union Geological-Reconnaissance Office (I.V. Kuznetsov, N.G. Popov), whose data provided the basis for the acceptance of the unified classification by the 1956 inter-departmental conference.

Ya.S. Zubrilin, A.M. Danilevich, and N.N. Predtetchenskiy (1952-1953) subdivided lower Carboniferous deposits into four formations (reading upward): $C^a{}_1$ — conglomeratic;[3] $C^b{}_1$ — a rhythmic alternation of light-colored sandstone and porcelain-like argillite; $C^c{}_1$ — alternation of greenish to yellow-gray sandstone and dark green to gray, in places mottled, siltstone; and $C^d{}_1$ — red-purple sandstone with intercalations of siltstone and limestone.

Fish scales of Acanthodes sp. and A. ex gr. lopatini were found by A.M. Danilevich in the $C^b{}_1$ formation (Biy-Khem River, below the mouth of Shivelig Creek), which, according to D.V. Obruchev, means that they are Carboniferous rather than Devonian as was believed by most geologists.

I.V. Kuznetsov and N.G. Popov (1955) designated seven formations in the lower Carboniferous of Tuva (reading upward): the Suglugkhemskaya represented chiefly by an alternation of pink-gray conglomerate, gravel beds, and coarse-grained sandstone; locally, there is a limestone bed on top, with Strepsodus

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[1] Novyye dannyye po stratigrafii i litologii nizhnego karbona Tuvy.

[2] In the scheme of these authors, the Arguzun formation is underlain by the Tannuol'skaya formation ($C^b{}_2$) which they relegated to the Middle Devonian. Its Upper Devonian age has been recognized since.

[3] The $C^a{}_1$ formation is subdivided into three members, $C_1^{aI}$, $C_1^{aII}$, and $C_1^{aIII}$.

siberiacus Chab.; the Dzhargin, made up of brownish lilac sandstone, siltstone, tuffite, and lenses of conglomerate; the Kherbes, presenting an alternation chiefly of yellow-gray sandstone, tuff, tuffite, siltstone, and shale; the Baytag, represented by motley to green-gray tuff, tuffite, sandstone, siltstone, and rare limestone; the Tebek, consisting of alternating brown-lilac sandstone, siltstone, tuff, tuffite, locally with isolated limestone beds; the Aktal', an alternation of gray, greenish to dark gray sandstone, siltstone, shale, tuff, tuffite, and rare limestone; and the Mooldykhemskaya, represented by lilac sandstone and tuffite. The authors mention that this formation is developed only in southwest Tuva, in the Western Tannu-Ola Range area.[4]

The only difference between this and the 1956 unified classification is that in the latter the Dzhargin formation is called Kyzylchirin; and the Tebek, the Ekkiottug.[5]

In 1956-1957, lower Carboniferous deposits of Tuva were studied by the author in collaboration with I.S. Borovskaya. From detailed study and description of the principal control sections in Central and Western Tuva, and from a microscopic study of rocks, we have obtained data for determining the lithologic facies features of lower Carboniferous deposits in that area. We also have determined the error of isolating the uppermost member of the unified classification — the Mooldykhemskaya formation — and we have subdivided some formations into smaller units, sub-formations. These formations are the Baytag, Kherbes, and Suglugkhemskaya.[6]

Given below is a new variant which we regard not as a substantially new scheme but as a refinement over the earlier one, unified according to data of I.V. Kuznetsov, Ya.S. Zubrilin, A.M. Danilevich, N.G. Popov, N.N. Predtetchenskiy, V.V. Volkov, and others.

The differentiation of stages has been done on the basis of paleontologic material and also from a correlation with the Minusinsk through the lower Carboniferous. The paleontology of the section will be given below, in the description of stratigraphic subdivisions. The problem of correlation of the lower Carboniferous in Tuva and in the Minusinsk trough is not considered in this paper.

In this work, unlike the previous studies, we studied microscopically, bed by bed, all the important sections; we have determined that the part of the lower Carboniferous section corresponding to the Kherbes and Baytag formations is represented by a two-fold rhythmic alternation of tuffaceous arenaceous to chiefly tuffaceous beds. We draw the contact between these two formations on a line between two full cycles.[7] The observed persistent rhythmic alternation of chiefly tuffaceous to tuffaceous arenaceous members in formations made it possible to subdivide the latter into the upper and lower sub-formations.

The Suglug-Khem formation, too, is marked by a clean-cut two-fold constitution; everywhere in its full section, i.e., where it is overlain by the Kyzylchirin formation, it is represented at the bottom by coarse clastics (sandstone and conglomerate), with chiefly limestone on top, carrying fish remains, Strepsodus siberiacus Chab. and the less common Rhizodopsis sp.

Our study has also shown that I.V. Kuznetsov, N.G. Popov, and V.V. Volkov, guided at the beginning of their study chiefly by the color of the rocks, erroneously assigned most of the Barshingol' and Mugur-Ulatay sections (lower slope of the Tannu-Ola Range) to the Ekki-Ottug formation, because of their red color in that area. They also erroneously assigned to the Aktal' a green tuffaceous arenaceous sequence at the top of the Baytag formation; and they assigned to a new Mooldy-Khemskaya formation the still higher red tuffite and sandstone, with a visible thickness of about 120 meters, as without an analogue in other areas of Tuva. The error of such correlation is ever so obvious because a regular "reddening" of the entire lower Carboniferous section of Tuva has been observed southwest of there. Thus, where only the Baytag formation becomes red on the northern Tannu-Ola slope (on On-Kazhaa River, Ak-Tal settlement), as compared with the central areas, a lilac-red color also marks the Kherbes and Sugluykhem formations on the southern slope of that range, in the Mugur-Ultay watershed, especially along the Barshiin-Gol creek.

Our correlation of the Tuva sections is based primarily on the regular alternation of chiefly clastic and tuffaceous sequences and on the petrographic composition of different

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[4] Simultaneously with I.V. Kuznetsov and N.G. Popov, the Mooldykhemskaya formation was named by V.V. Volkov and G.P. Tolmachev (the VSEGEI geologists).

[5] It has been decided to assign the name, Dzhargin, to the uppermost red Upper Devonian formation.

[6] Sub-formations of the Suglug-Khem formations were first designated by A.M. Danilevich and N.N. Predtechenskiy (sub-formations $C^a{}_1I$ and $C^a{}_1II$).

[7] The Kherbes — Baytag boundary so drawn coincides with the boundary between formations $C^b{}_1$ and $C^c{}_1$ of Ya.S. Zubrilin, A.M. Danilevich, and N.N. Predtetchenskiy. I.V. Kuznetsov and N.G. Popov draw this line somewhat higher.

| Division | Stage | Formation | Sub-formation |
|---|---|---|---|
| Upper Paleozoic or Jurassic deposits | | | |
| | | Break | |
| Lower Carboniferous — $C_1$ | Visean—$C_1^v$ | Aktal' — $C_1^{ak}$ | |
| | | Ekki-Ottug — $C_1^{ek}$ | Upper Baytag — $C_1^{bt2}$ |
| | | Baytag — $C_1^{bt}$ | Lower Baytag — $C_1^{bt1}$ |
| | Tournaisian(?)-Visean(?) | Kherbes — $C_1^{hr}$ | Upper Kherbes — $C_1^{hr2}$<br>Lower Kherbes — $C_1^{hr1}$ |
| | | Break | |
| | Tournaisian—$C_1^t$ | Kyzylchirin — $C_1^{kz}$ | Upper Suglugkhem — $C_1^{sgl2}$ |
| | | Suglugkhem — $C_1^{sgl}$ | Lower Suglugkhem — $C_1^{sgl1}$ |
| | | Break | |
| Upper Devonian —$D_3$ | Famennian—$D_3$ | Dzhargin — $D_3^{dg}$ | |

stratigraphic subdivisions. Paleontologic material, because of its scarcity, could not be used in the differentiation and correlation of sections.

Given below is a brief description of stratigraphic subdivisions.

## THE SUGLUGKHEM FORMATION $C_1^{sgl}$

A formation so named was first mentioned by I.V. Kuznetsov and N.G. Popov (1955). It corresponded to the upper part of Z.A. Lebedeva's Shivilk formation and to the two lower sub-formations of the basal $C^a{}_1$ formation of A.M. Danilevich and others.

The type locality of the Suglugkhem formation is on the right bank of Suglugkhem River (right tributary of the Ulu-Khem), 2 to 3 kilometers above the mouth, where the river, cutting the Kherbes Mountain, forms the so-called Kamennyye Vorota (Stone Gate). This formation is subdivided into two sub-formations: the Lower Suglugkhem, terrigenous, chiefly coarsely clastic; and the Upper Suglugkhem, made up chiefly of limestone with a typical fish fauna.

The Lower Suglugkhem sub-formation, $C_1{}^{sgl}$, is represented by pinkish yellow, yellow- to green-gray, gray, and less common lilac-colored sandstone, gravel, conglomerate, and red-brown siltstone. There are strictly subordinate limestone and tuffaceous rocks (Fig. 1).

The sandstones are unevenly-grained, polymictic, commonly arkosic, in places graywackes. They are marked by poor sorting and rounding of grains, an intense regeneration of quartz and feldspar, and a nearly complete lack of tuffaceous material. Conglomerates usually are made up of fine pebbles, less commonly of medium- to coarse-pebbles. They usually consist of extrusive, less commonly of intrusive and siliceous rocks and quartz. Fragments of sedimentary, most likely Devonian redbeds, commonly occur but in small amounts. The pebbles are 1 to 5 centimeters, seldom up to 30 centimeters in diameter. The cement usually is sandy calcitic. Tuffaceous rocks carry albitized, in places ferruginous, less commonly chloritic varieties. Limestones are micro- to finely-crystalline, locally recrystallized to coarse-grained.

The lower boundary of the sub-formation coincides with the Carboniferous-Devonian boundary. Generally, it is drawn very tentatively on the change of the lilac-red color typical of Upper Devonian rocks (Dzhargin formation) to the predominating yellow-gray, pink-yellow, or gray color of the Suglugkhem rocks. The latter formation locally rests with sharp angular unconformity of D-$C_m$ rocks. This takes place in the Suglugkhem type locality on the Suglumkhem River (Kherbes Mountain), also in the Dzharga Mountains ($D_3$), the Ak-Tag Mountains, the upper course of Suglugkhem, in the Aryg-Uzu basin ($Pz_1$), and some other places. As a rule, the lower Suglugkhem subformation is overlain conformably by the

Upper Suglugkhem. In that event, the upper boundary of the lower sub-formation is readily determined on the appearance of greenish gray limestone typical of the upper sub-formation. Because of pre-Kherbes erosion, the lower Suglugkhem sub-formation is often overlain directly by the Kherbes formation.

In such an event, the upper boundary of this sub-formation is even more distinct because of the substantially different lighology of the Kherbes formation.

Facially, the Lower Suglugkhem sub-formation is very inconsistent, with three facies types identified in it in the area of Western and Southwestern Tuva (Fig. 2). Type One — the Shivelig — is represented by a rhythmic alternation of yellow- to pink-gray conglomerate, sandstone, and red-brown siltstone, with isolated beds of green tuff. This type is developed in the northeastern part of the area, on both banks of Biy-Khem River (Shivelig and Kamennyy Klyuch Creeks), also on the right bank of Suglugkhem River (Ekki-Ottug Creek, the Dzharga Mountain, the upper course of Suglugkhem River). Type Two — the Kherbes — is represented by yellow-gray sandstone, often showing a pinkish to greensih tint, and by subordinate conglomerates. Neither the red siltstone nor the tuffaceous rocks have been observed here. The second facies type of the Lower Suglugkhem sub-formation is typical of the Ulu-Khem right bank, in and below the Kherbes Mountain; also of the entire left bank of that river — in the Aktal' and Onkazhinsk coal troughs. The third type of the Lower Suglugkhem sub-formation is known only from the right bank of Barshiin-Gol River, where it is represented chiefly by lilac-colored to light green- and yellow-green, mixed-grained sandstone with subordinate red- to lilac-brown sandstone and subordinate red to lilac-brown tuff and occasional dark gray to almost black limestone.

This formation is poor in organic remains. The only identifiable flora has been found by the author, in 1955, in the type locality for the Suglugkhem formation, in a lenticular bed of green sandstone, about 60 meters below the top. Lepidodendropsis hirmeri Lutz., L. vandergrachti Jongm. Goth et Darr, and L. Steinmanni Jongm. have been identified from there by A.R. Anan'yev and Yu.V. Mikhaylova. They state that, from this flora, the Suglugkhem formation is definitely correlative with the Tournaisian flora of Central Germany, Egypt, Southeastern China, and North and South America.[8] The thickness of this sub-formation ranges from 0 to 520 meters.

The Upper Suglugkhem sub-formation, $C_1sgl_2$, is made up of green-gray, gray, in places pinkish gray limestone and subordinate gray, less commonly brown, often calcareous siltstone, sandstone, conglomerate, and tuffite. The limestones are micro- to fine-grained, locally recrystallized to coarse-grained, occasionally siliceous, and containing additions of clastic material.

Sandstone of this sub-formation does not differ from the Lower Suglugkhem. The tuffs, observed only in the On-Kazhaa River section, have been altered by secondary processes of silicification and chloritization. The upper and the lower boundaries of this sub-formation are fairly sharp. In exposures where it is overlain by the Kyzylchirin formation (Kherbes and Dzharga Mountains, On-Kazhaa River), the boundary is fixed on a sharp change in color and lithology: the Kyzylchirin formation is marked by the nearly complete lack of limestone and by the presence of tuff, commonly mottled, and by its predominately red color. Where that formation is missing, probably because of a pre-Kherbes erosion, the Upper Suglugkhem - Kherbes contact is drawn on the first appearance of the typical gray to yellow-gray tuff and tuffite, interbedded with sandstone.

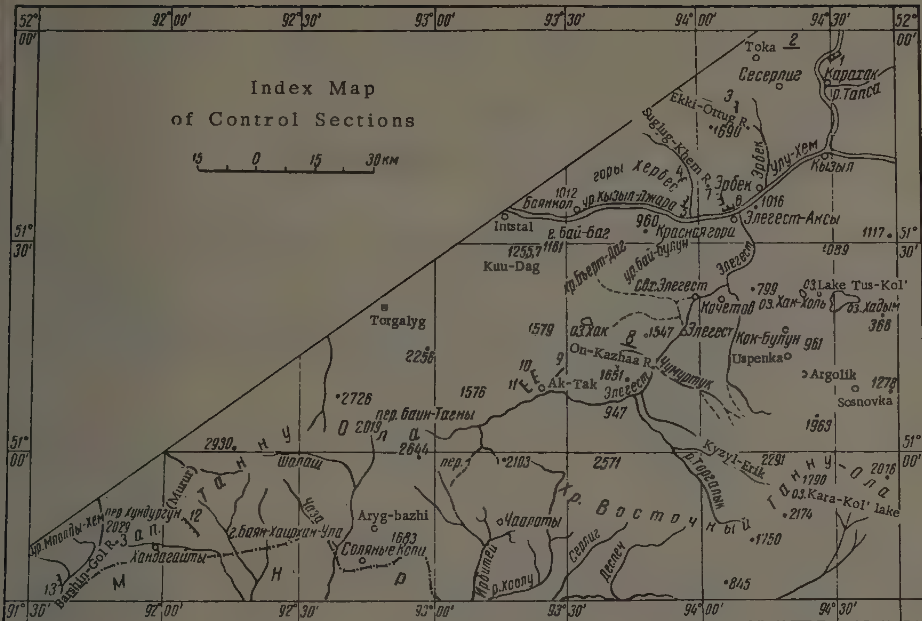
In the northeast of the area under study (Malyy Shivelig, Kamennyy Klyuch, Ekki-Ottug Creeks; northern limb of the Dzhargin brachianticline), as well as in the Mugur-Ulatai watershed, this sub-formation is missing, probably also because of a pre-Kherbes erosion. Everywhere else in the area, it is represented on the whole by two types of sections. The first is associated with the right bank of the Ulu-Khem River where it is represented on the whole by a rather thin (up to 20 meters) body consisting chiefly of greenish gray limestone with fish remains, Strepsodus siberiacus Chab. and Rhizodospis savenkovi Obr.

This sub-formation is quite different on the left bank of Ulu-Khem River. In the Onkazhinsk and Aktal' depressions, it is represented by alternating limestones like those described above, and by mixed-grained sandstone, conglomerate, and less commonly tuffs. Its thickness in those two areas is 95 and 80 meters, respectively.

Still farther west, along Barshiin-Gol Creek, it is represented by dark gray to almost black limestone with subordinate light green to pink-brown mixed-grained sandstone and gray to green thick-bedded siliceous tuff, 54 meters thick. V.V. Volkov has found scales of Strepsodus siberiacus Chab. in limestone of this formation.

Ichthyofauna of this sub-formation is

[8] All determinations of fauna from the Suglugkhem and overlying formations, by A.R. Anan'yev and Yu. V. Mikhaylova, are preliminary.



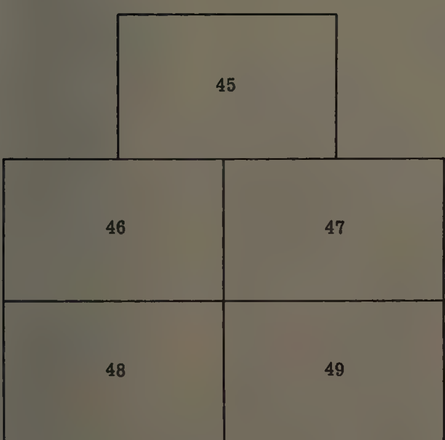




Figure 1 appeared in the Russian journal as a large fold-out sheet. To avoid losing detail, this Figure was split into five pages. The arrangement of pages in relation to the original Figure is shown in the box at left. The map above begins Figure 1.

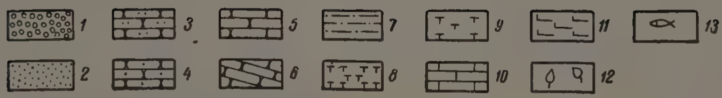
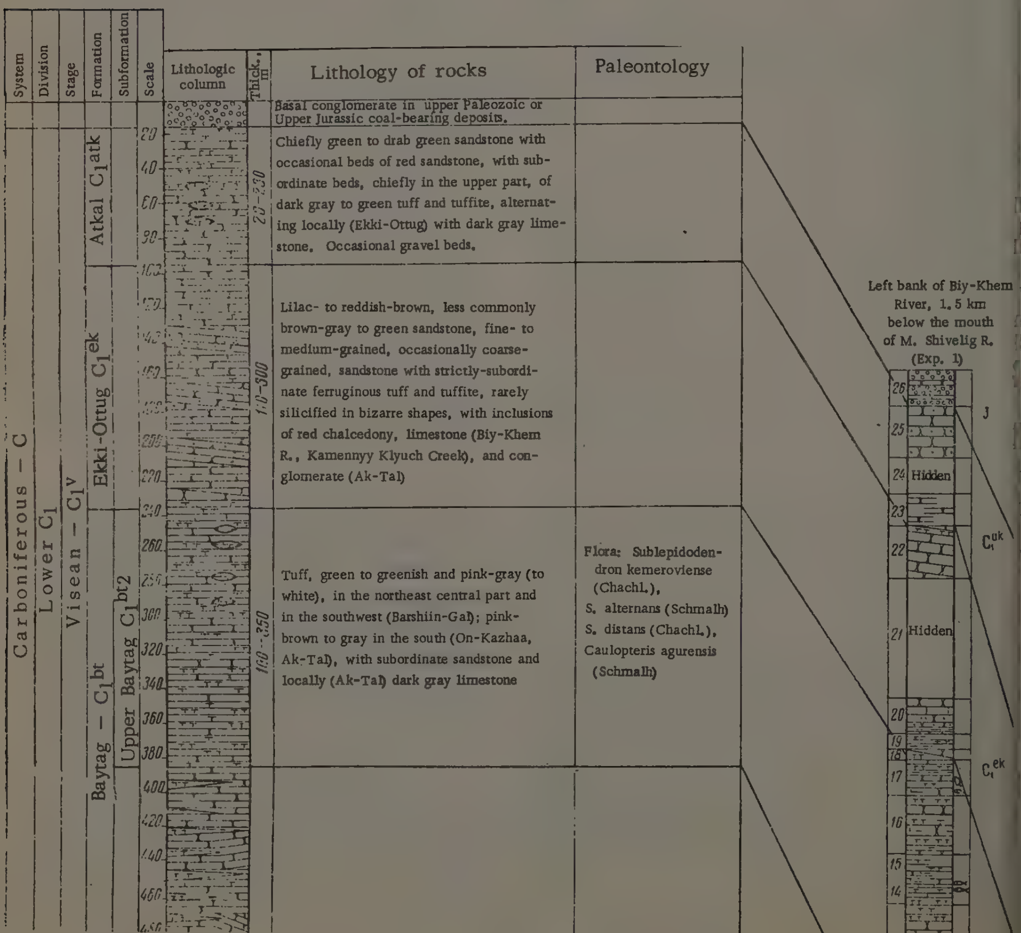
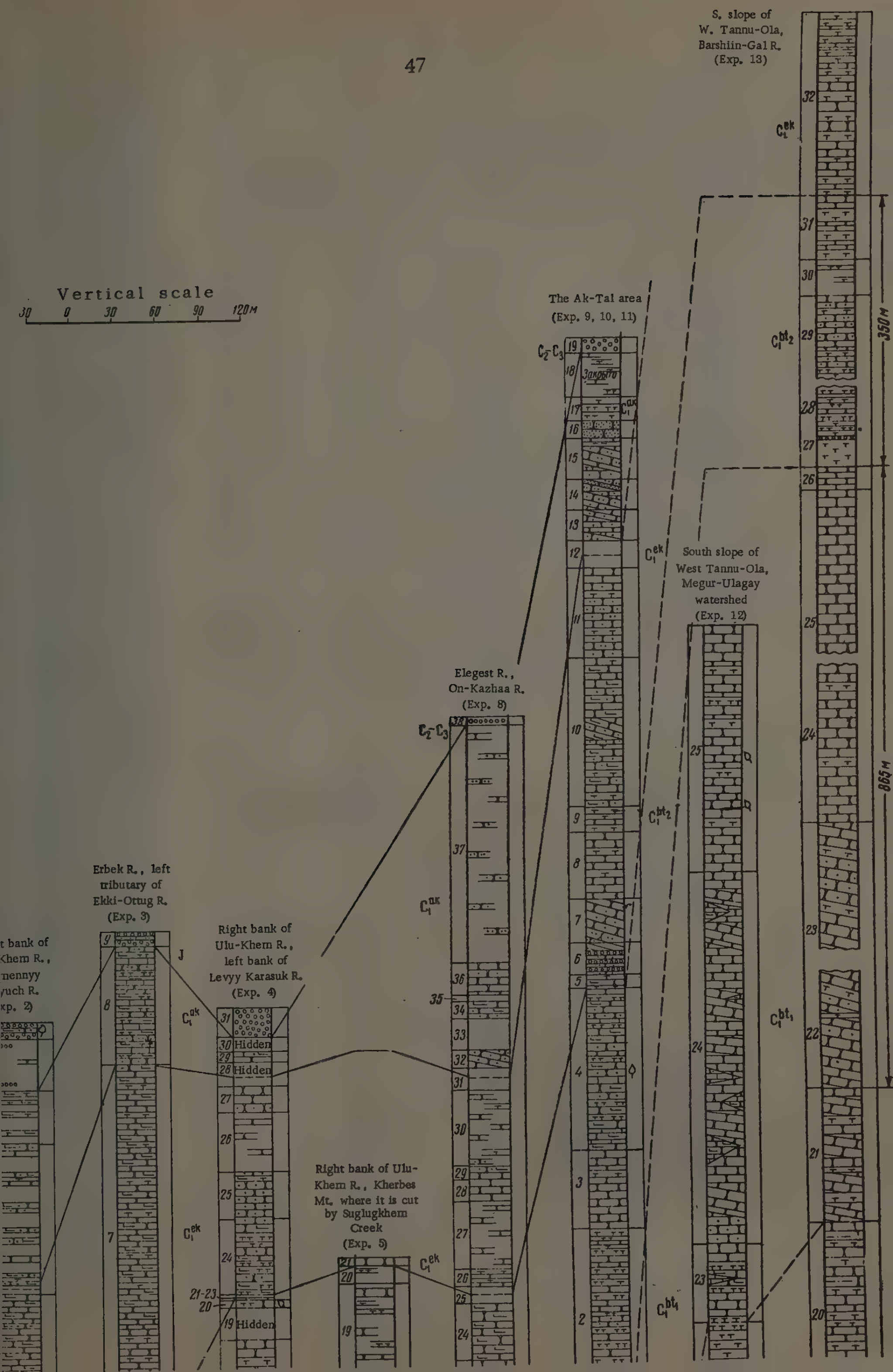


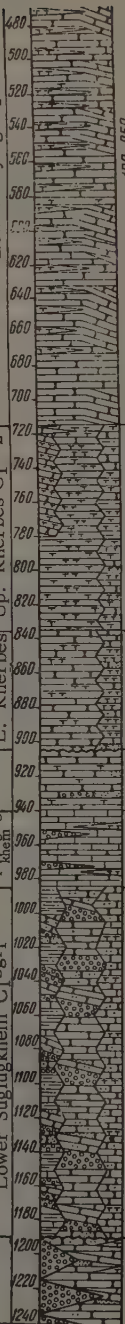

FIGURE 1. Correlation of control sections and a composite stratigraphic section of the Tuva lower Carboniferous (M. Grayzer and I.S. Borovskaya, 1957).

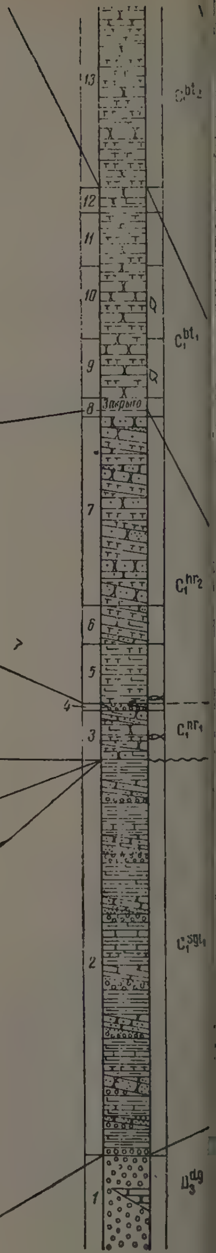
1 -- conglomerate; 2 -- gravel beds; 3 -- coarse-grained sandstone; 4 -- medium-grained sandstone; 5 -- fine-grained sandstone and silty sandstone; 6 -- cross-bedded sandstone; 7 -- siltstone; 8 -- tuff; 9 -- tuffite; 10 -- limestone; 11 -- calcareous rocks; 12 -- plant remains; 13 -- fish remains. In exposure 13, the thickness of the Lower Suglugkhem subformation and of Baytag formation are not according to scale (see figures on the left).

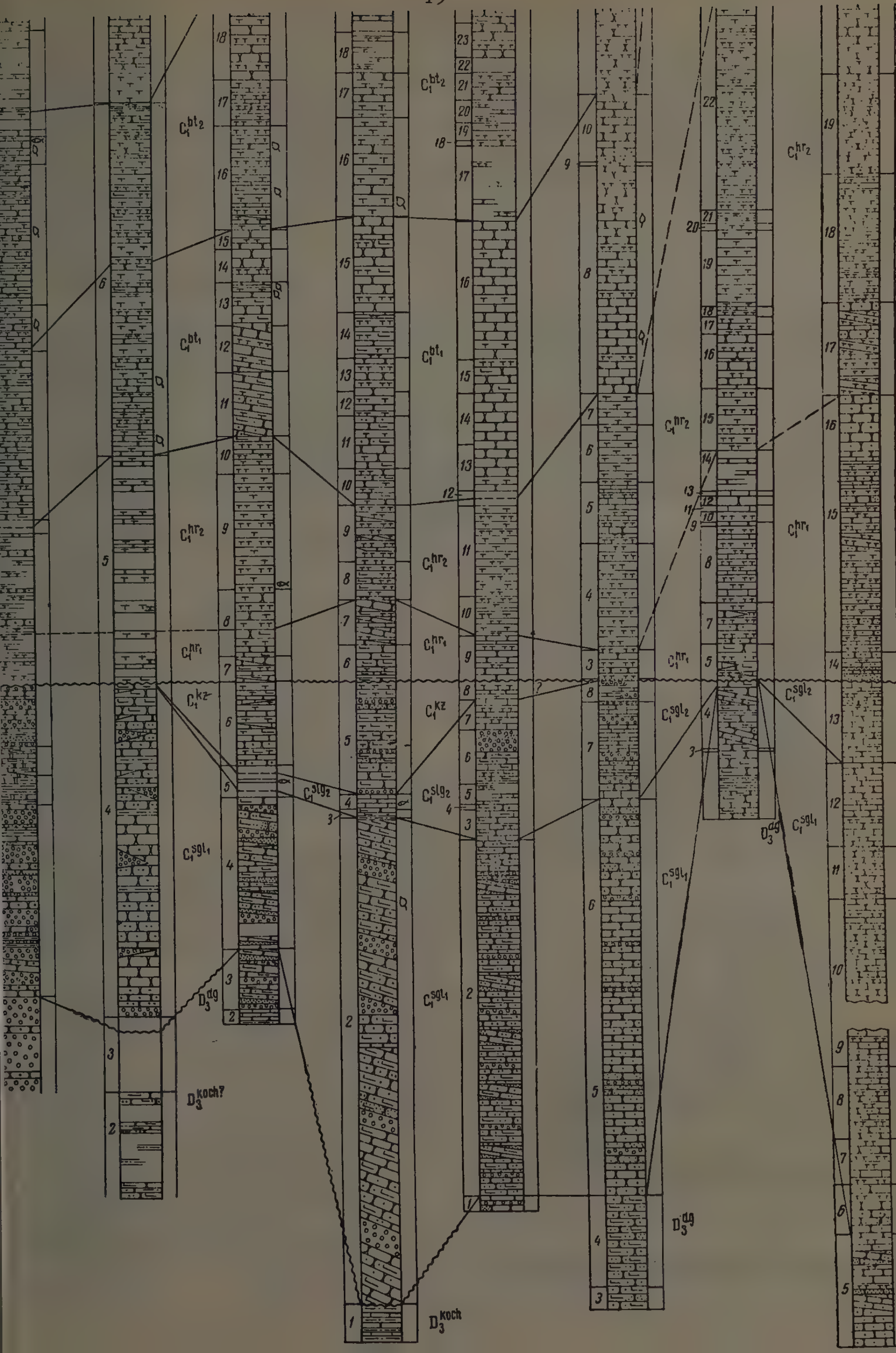



Vertical scale
30 0 30 60 90 120м
S. slope of W. Tannu-Ola, Barshiin-Gal R. (Exp. 13)
The Ak-Tal area (Exp. 9, 10, 11)
South slope of West Tannu-Ola, Megur-Ulagay watershed (Exp. 12)
Elegest R., On-Kazhaa R. (Exp. 8)
Erbek R., left tributary of Ekki-Ottug R. (Exp. 3)
t bank of Khem R., nennyy yuch R. xp. 2)
Right bank of Ulu-Khem R., left bank of Levyy Karasuk R. (Exp. 4)
Right bank of Ulu-Khem R., Kherbes Mt. where it is cut by Suglugkhem Creek (Exp. 5)
Hidden
Hidden
Hidden
350м
865м
J

| System | Series | Stage | Formation | Subformation | Thickness, m | Lithology | Fossils |
|---|---|---|---|---|---|---|---|
| Carboniferous – C | Lower $C_1$ | Visean $C_1^v$ | Baytag $C_1^{bt}$ | Lower Baytag $C_1^{bt1}$ | 100–950 | Sandstone, green to greenish and pink-gray, locally almost white, less commonly (chiefly in the southwest) pink-brown, with subordinate tuff and tuffite | Flora: Sublepidodendron kemeroviense (Chachl.), S. alternans (Schmalh.) |
| | | Tournaisian (?)–Visean(?) | Kherbes $C_1^{hr}$ | Up. Kherbes $C_1^{hr2}$ | 60–330 | Tuff and tuffite, green-gray to yellow-gray (to white), locally (Barshiin-Gal Creek) lilac-brown, mostly siliceous, porcelain-like, less commonly mottled, with strictly subordinate polymictic mixed-grained sandstone, at times siltstone (south slope of west Tannu-Ola) and micro- to fine-grained, less commonly (Ak-Tal) recrystallized limestone | Ichthyofauna: Cycloptyhius sp. |
| | | | | L. Kherbes | 20–240 | Sandstones, green-gray to yellow-gray, at times lilac-brown, polymictic, fine-medium-grained, with subordinate intercalations of siliceous, often thin slaty tuff and tuffite with rare lenses of limestone. Occasional gravel and conglomerate at the base of the formation | Ichthyofauna: Acanthodes sp., Ganolepis sp. |
| | | Tournaisian $C_1^t$ | Kyzylchi-rink $C_1^{kz}$ | | 0–75 | Sandstone, brown to red-brown, with subordinate conglomerate and tuffaceous rocks. | |
| | | | Suglugkhem $C_1^{sgl}$ | Up. Suglug-khem | 0–95 | Limestone, green-gray to gray, locally pink-gray, with subordinate gray to brown siltstone, sandstone, conglomerate and tuffite | Icthyofauna: Strepsodus siberiacus Chab. Rhizodopsis savenkovi Obr. |
| | | | | Lower Suglugkhem $C_1^{sgl1}$ | 0–520 | In the northeast (Biy-Khem, Kamennyy Klyuch), a rhythmic alternation of yellow-gray to pink-gray conglomerate and sandstone, with red-brown, locally green-spotted, siltstone. Occasional beds of red-brown limestone and green tuffs. In central part (Ulu-Khem basin), sandstone and conglomerate, yellow-gray, often with a pink or green hue. Conglomerates are lenticular and decidedly subordinate. In the southwest (south slope of west Tannu-ola), lilac- to greenish or yellow-gray sandstone, unevenly-grained, with subordinate red- to lilac-brown tuff and occasional beds of dark gray to almost black limestone | Flora: Lepidodenaropsis hirmeri Lutz., L. vandergrachti Tongm. Qoth. et Darr., L. Steinmanni Jongm |
| Devonian | Upper $D_3$ | Famennian $D_3^2$ | Dzhargin $D_3^{dg}$ | | | | |




$C_1^{bt_2}$
$C_1^{bt_1}$
$C_1^{hr_2}$
$C_1^{hr_1}$
$C_1^{kz}$
$C_1^{slg_2}$
$C_1^{sgl_1}$
$C_1^{sgl_2}$
$D_3^{dg}$
$D_3^{koch?}$
$D_3^{koch}$

similar to that from the Bystryanka fauna in the Minusinsk trough. That formation is assigned by most students to the very base of the Carboniferous. The Upper Suglugkhem sub-formation ranges from 0 to 95 meters thick. The thickness of the entire Suglugkhem formation ranges from 0 to 575 meters.

## THE KYZYLCHIRIN FORMATION $C_1^{kz}$

The Kyzylchirin formation corresponds to the upper sub-formation of the basal lower Carboniferous formation, designated by A.M. Danilevich, and to the Dzhargin formation of I.V. Kuznetsov and N.G. Popov.[9] Its type section is located on the southwestern limb of the Dzhargin anticline (right bank of Ulu-Kham River, northwest of the former mining settment of Urgoy-Shakhtazy). In addition, this formation is well exposed in Kherbes Mountain — along the right bank of the Suglugkhem and on the left bank of Levyy Karasuk Creek.

These sections, concentrated in a comparatively small area on the right bank of the Ulu-Khem, are just about the only exposures with definitely Kyzylchirin rocks. As a rule, this formation is missing in other areas, which most probably is accounted for by the regional character of the pre-Kherbes erosion.

The Kyzylchirin formation is made up of brown to red-brown sandstone with subordinate conglomerate and tuffaceous rocks. Occasionally it carries isolated lentils of limestone (Kherbes, Levyy Karasuk Creek). It is overlain by the Kherbes formation, whose contact is determined by the Kyzylchirin red-brown sandstone and tuff changing abruptly to light-colored arenaceous tuffaceous rocks of the overlying Kherbes formation.

Sandstones of the Kyzylchirin formation are polymictic, fine- to mixed-grained, strongly ferruginous. The fragments are usually poorly rounded. Unlike the Suglugkhem sandstone, grains of quartz and feldspars are usually unregenerated, with tuffaceous material always present along with calcite in the cement. Tuffaceous units of this formation differ from the Suglugkhem in their comparatively well preserved original structure. Present among them are siliceous and albitized varieties, almost always ferruginous.

From east to west and north (from type locality in the Dzhagra Mountain to exposures in the Kherbes Mountain, along the Suglugkhem and the Levyy Karasuk Creek), there is a considerable decrease in the amount of conglomerate and in the sandstone grain size. Isolated lentils of limestone appear in the northernmost of the three above-named exposures. Organic remains are unknown in the Kyzylchirin formation. Its thickness ranges from 0 to 75 meters.

[9] As pointed out before, the name, Kyzylchirin formation, appears first in the unified scheme.

## THE KHERBES FORMATION $C_1^{hr}$

These deposits were first identified as the $C^b{}_1$ formation, by Ya.S. Zubrilin and A.M. Danilevich. The present name was assigned to them in 1955 by I.V. Kuznetsov, and N.G. Popov. It corresponds to the lower part of the Zvenyashchaya formation of Z.A. Lebedeva. Its type section is located along the Suglugkhem where it cuts the Kherbes Mountain to form the Kamennyye Vorota (Stone Gate).

The Kherbes is the best developed lower Carboniferous formation in the Tuva area.

As mentioned before, it rests transgressively, with sharp angular unconformity, on underlying lower Carboniferous deposits. It frequently rests directly on older formations, as well, from Upper Devonian down to and including the Cambrian. Only in the Kherbes Mountains area and in their vicinity, on the western slope of Dzhagra Mountain, i.e., in a very small portion of the Tuva area, is the Kherbes formation underlain by definitely Kyzylchirin deposits. Even in these places there is no certainty that there has not been any break.

The Kherbes formation is made up chiefly of yellow, gray, light green, white, in places red-brown siliceous, commonly porcelain-like tuff and tuffite and subordinate fine, less commonly medium-grained sandstone primarily in its lower part, and of gray, dark gray, and green limestone.

The tuffaceous rocks are represented by several varieties, the most common being light colored tuff and occasional tuffite, strongly altered by albitization and chloritization (Central and Southern Tuva — the Kherbes Mountain, West Tannu-Ola Range). Also very numerous are siliceous and chloritic tuff and tuffite. Such formations are most common in the north and northeast Central Tuva (Shivelig, Kamennyy Klyuch, Ekki-Ottug Creeks). There are isolated occurrences of ferruginous albitized and siliceous tuffaceous rocks, colored brown for this reason; and of albitized tuff carrying a considerable amount of organic matter which accounts for its dark gray, almost black, color.

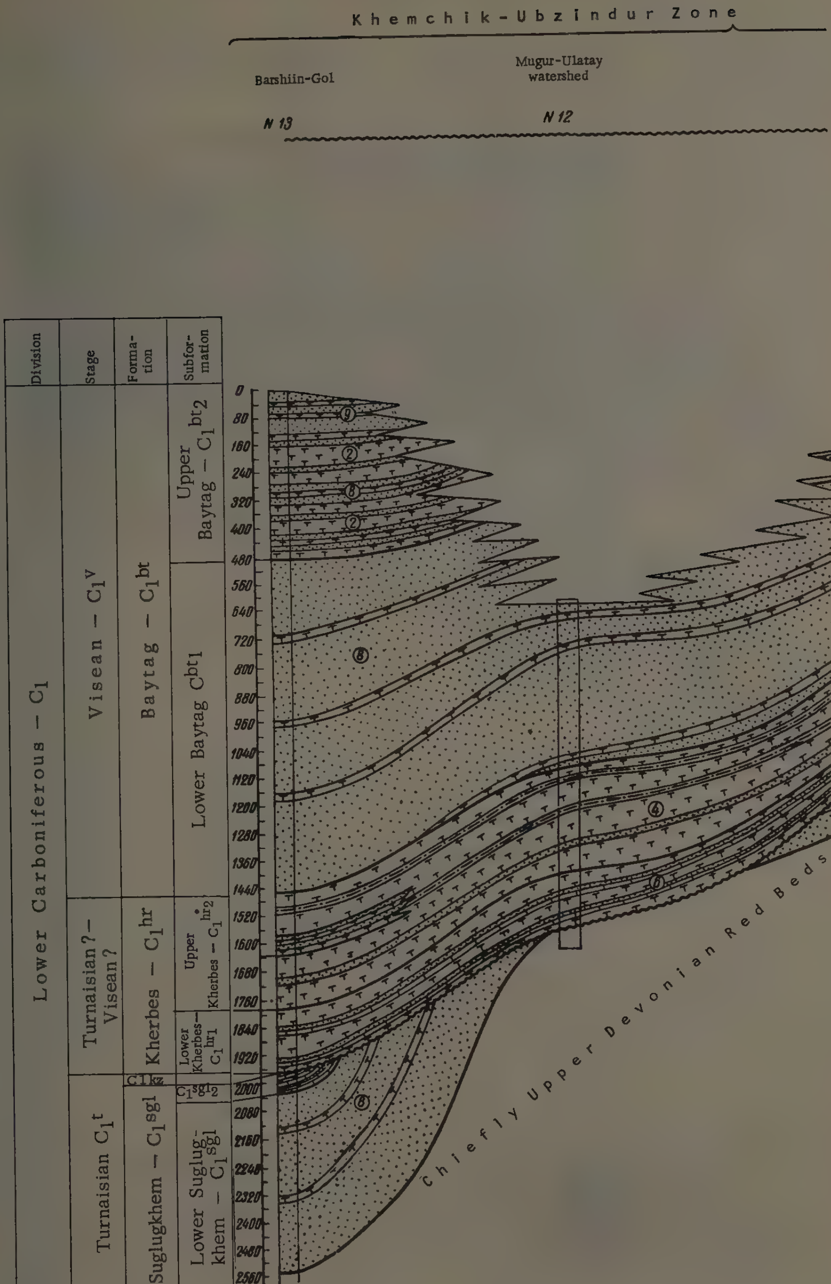



FIGURE 2
(caption on pages 52 and 53)

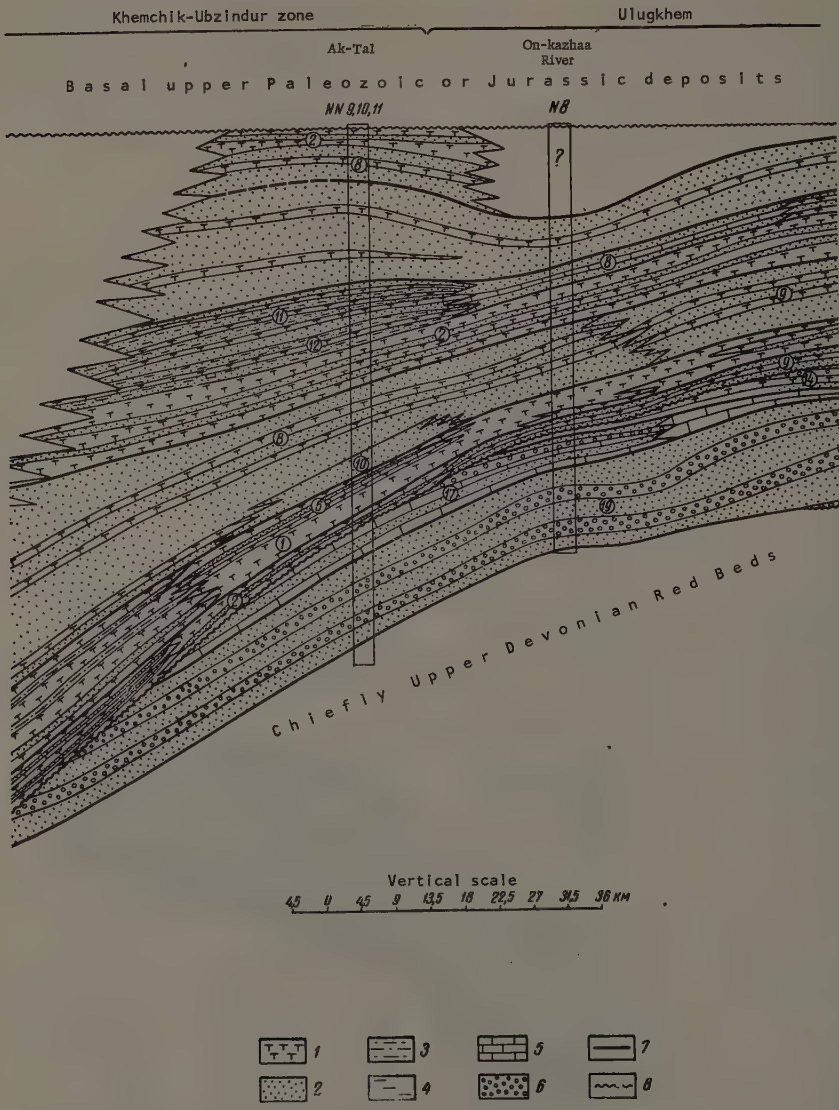
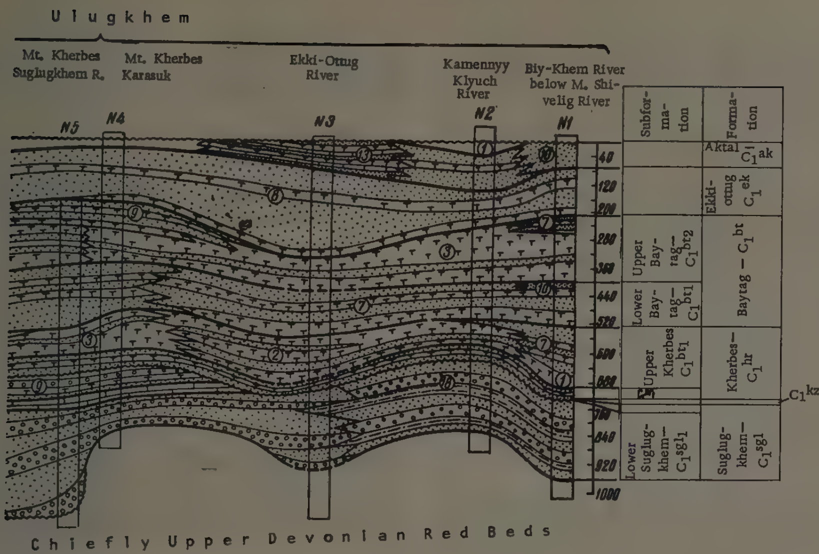



FIGURE 2. Longitudinal lithologic facies section of lower Carboniferous deposits in the Tuva middle-upper Paleozoic trough (M.I. Grayzer, 1957).

Numbers in legend: 1 -- tuffaceous rocks; 2 -- sandstone; 3 -- siltstone; 4 -- silty sandstone; 5 -- limestone; 6 -- conglomerate 7 -- normal stratigraphic contact; 8 -- unconformity.




Lithologic facies zones (figures in circles): 1 -- tuffaceous rocks; 2 -- same with subordinate sandstone; 3 -- same with extremely subordinate sandstone; 4 -- same with strictly subordinate siltstone; 5 -- same with subordinate limestone; 6 -- same with subordinate sandstone and limestone; 7 -- alternating tuffaceous rocks and sandstone; 8 -- sandstone with strictly subordinate tuffaceous rocks; 9 -- sandstone with subordinate tuffaceous rocks and occasional conglomerate; 10 -- sandstone; 11 -- silty sandstone and sandstone with subordinate tuffaceous rocks and occasional limestone beds; 12 -- silty sandstone with subordinate tuffaceous rocks; 13 -- alternating sandstone, tuffaceous rocks, and limestone; 14 -- limestone with subordinate tuffaceous rocks; 15 -- limestone with subordinate sandstone; 16 -- limestone with subordinate tuffaceous rocks and sandstone; 17 -- alternating limestone, sandstone and conglomerate; 18 -- alternating sandstone, conglomerate, and siltstone; 19 -- sandstone with subordinate conglomerate.

Sandstone of the Kherbes formation also is very diversified, with tuffite polymictic varieties the most common. They differ from the underlying ones by better sorting and rounding of clastic grains. The sandstone is most often fine-grained, with medium-grained varieties less common and with occasional mixed-grained types. As in most of the older sandstones, feldspar grains dominate over the quartz grains and other rock fragments. Feldspars and quartz are often regenerated, which renders the sandstone somewhat like the Suglugkhem. The concentration of sandstone in the lower part of this formation makes it possible, in nearly all sections and especially if they are well exposed, to identify two sharply differing sequences: the lower tuffaceous-arenaceous, and the upper chiefly tuffaceous. Accordingly, we have designated two sub-formations: the Lower and the Upper Kherbes. Limestone of the Kherbes formation is most likely the older one.

The Lower Kherbes sub-formation $C_1^{hr1}$ is represented in the main by polymictic sandstone, fine to occasionally medium-grained, with subordinate siliceous, often thin slaty tuff and tuffite, with rare limestone in the southwest (southern slope of West Tannu-Ola Range). Occurring mostly at the base are gravel and small-pebble conglomerate. Most rocks are greenish to yellowish gray, occasionally lilac-brown (Barshiin-Gol Creek).

The sub-formation lower boundary coincides with the base of the entire Kherbes formation and is very distinct, as already mentioned. Its upper boundary is not as distinct. It is drawn on the change (fairly rapid in some places; rather gradual in some others) from its tuffaceous-arenaceous rocks to tuff and tuffite of the upper sub-formation.

In all Central Tuva sections and in the Onkazhinsk trough, the Lower Kherbes sub-formation has a very similar lithology, being everywhere represented by sandstone with strictly subordinate tuff and tuffite, and with isolated limestone lentils, in a few places (Kherbes Mountain, on Suglugkhem River).

In the Aktal' trough, this sub-formation consists primarily of tuff, with sandstone being subordinate. In the Mugur-Ulatay watershed, the Lower Kherbes sub-formation, despite the abrupt increase in thickness, differs but little from its northeastern exposures. The main feature of the extreme southwestern exposure of this sub-formation (along Barshiin-Gol Creek) is its lilac color.

We have found fish scales in tuffite of this sub-formation, cropping out at the Malyy Shivelig Creek. They were determined by A.A. Matveyeva (Paleontologic Institute, Academy of Sciences, U.S.S.R.) as Acanthodes sp. and Ganolepsis sp., known from the Bystryanka formation of the Minusinsk trough and from the Carboniferous and Permian of Australia and Scotland.

The thickness of the Lower Kherbes formation in Central Tuva ranges from 20 to 55 meters. It increases going southwest, to 150 meters in the Mugur-Ulatay watershed, and to 240 meters along Barshiin-Gol Creek.

The Upper Kherbes sub-formation $C_1^{hr2}$ is made up mostly of siliceous, porcelain-like, less commonly mottled, tuff and tuffite with strictly subordinate polymictic mixed-grain sandstone, siltstone, and micro- to finely crystalline limestone, commonly recrystallized.

The upper sub-formation boundary is fairly distinct in outcrop, being marked by the change of tuffaceous Kherbes deposits, light-colored, mostly siliceous and in places porcelain-like, to sandy or mostly sandy rocks in the lower part of the Baytag sub-formation above.

This formation is fairly diversified in facies. In Central Tuva, including the left bank of Biy-Khem River, it is made up of tuff and tuffite locally containing strictly subordinate fine-grained tuffite and cross-bedded sandstone. As exposed on the left bank of the Biy-Khem, below the mouth of Malyy Shivelig, it shows a marked increase in sand beds in its middle and upper parts, as compared with the preceding area. One of its features at Ak-Tal' is the presence of limestone in its middle part, also the predominantly gray color of its tuffaceous rocks. The Upper Kherbes sub-formation undergoes its greatest change to the southwest, on the south slope of the West Tannu-Ola Range. It becomes mostly red along Barshiin-Gol Creek, with a sizable increase in sand beds.

Thin-bedded tuffite at the base of the Upper Kherbes sub-formation, in the Biy-Khem outcrop, carry many scale and bone imprints of Cycloptychius sp., a genus of fish known from the Bystryanka formation, the Minusinsk trough.

The Upper Kherbes sub-formation is 60 to 170 meters thick in Central Tuva. To the southwest, it increases to 330 meters, along Barshiin-Gol Creek. The overall thickness of this sub-formation ranges from 115 to 515 meters.

## THE BAYTAG FORMATION $C_1^{bt}$

Baytag deposits were first described as formation $C_1^{bt}$ by Ya.S. Zubrilin and A.M. Danilevich. They were given the name Baytag

by I.V. Kuznetsov and N G. Popov, from the Baytag Mountains on the right bank of the lower course of Bayan-Gol River, a right tributary of the Ulu-Khem. However, because of the nature of the outcrops, the type locality is more appropriately in the Kherbes Mountain, on Suglugkhem River. Baytag deposits are almost as widely distributed as the underlying Kherbes on which they rest everywhere without any evidence of a break.

This formation is made up of green (of various hues), less commonly brown, sandstone and tuffaceous rocks with isolated limestone beds. The tuff and tuffite here are very similar to those of the Kherbes formation, differing from them only in a better preservation of the ash structure and in a somewhat more intense chloritization of volcanic glass. Limestone in this formation is very variable, having micro- to finely crystalline and mixed- to coarse-grained varieties. There are isolated occurrences of oolitic limestone with remains of Charaphyceae algae (Biy-Khem River, Kamennyy Klyuch Creek).

Like the Kherbes, the Baytag formation has a dual structure throughout its area of development. Its lower part, designated the Lower Baytag sub-formation, consists chiefly of limestone; the upper part, the Upper Baytag sub-formation, is represented chiefly by tuffaceous layers.

The Lower Baytag sub-formation $C^{bt1}$ is made up of green, greenish to pink-gray, locally almost white, less commonly brownish to lilac-brown sandstone with subordinate tuff and tuffite.

Its upper boundary is drawn on the appearance, going down, first of a thick tuffaceous member which is the base of the overlying sub-formation. The main facies feature of this sub-formation is the change in its color, to the southwest, from the predominantly green to mostly brown and lilac-red.

From the Biy-Khem, Kherbes, and Levyy Karasuk outcrops of this sub-formation, we have collected a flora which A.R. Anan'yev and Yu.V. Mikhaylova tentatively identified as Sublepidodendron kemeroviense (Chacl.) and S. Alternans (Schmalh.). The first form is known from the top of the Upper Tomsk and the base of the Ostrog formation in the Kuzbas (upper part of the Visean stage); the second has been determined from the Samokhval'sk formation at the base of the Visean in the Minusinsk trough.

The Lower Baytag sub-formation is 90 to 100 meters thick in Central Tuva and the Onkazhinsk trough; 253 meters at Ak-Tal settlement; 415 meters in the Mugur-Ulatay watershed (incomplete section); and 950 meters along Barshiin-Gol Creek.

The Upper Baytag sub-formation $C_1^{bt2}$ is represented by green, greenish or pinkish gray to almost white, brown and lilac-brown tuff with subordinate sandstone and occasional limestone.

Its upper boundary is drawn mostly on an abrupt change in the predominantly green color of Baytag rocks to the vidid brown of the overlying Ekki-Ottug formation. A change in lithology practically coincides with this boundary, with sandy tuffaceous Baytag rocks changing upward to mostly sandy Ekki-Ottug rocks. Tuff and tuffite are present only at the very base of the latter where they make up a thin unit, up to 20 meters thick.

The facies changes in this sub-formation are represented on the whole by a fairly distinct change in the green and gray typical of Central Tuva to a predominantly brown (with pinkish to lilac hues) on the northern slope of the West Tannu-Ola Range (On-Kazhaa River, Ak-Tal settlement). A distinctive feature of the Ak-Tal section is the presence in its upper part of isolated beds of dark gray limestone.

A section of this sub-formation in the area of Barshiin-Gol and Mooldykhem Rivers is similar on the whole, in its aspect and composition, to the central area sections. Despite that, as mentioned before, some geologists correlated this sequence with the stratigraphically higher Aktal formation of other areas of Tuva.

Fish scales were found in some exposed beds of the Biy-Khem; according to A.A. Matveyeva, they belong to one or several new genera of paleoniscids.

A.R. Anan'yev and Yu.V. Mikhaylova have identified the following from our collections: Sublepidodendron kemeroviense (Chacl.), Biy-Khem River outcrop; S. alternans (Schmalh) and Caulopteris ogurensis (Scmalh.), Kherbes Mountain by Levyy Karasuk Creek); and Sublepidodendron distans (Chachl.), Kherbes Mountain at Suglugkhem River. The two first forms also were encountered in the Lower Baytag formation; the last two, not found in the other Tuva units, are very typical of the Minusinsk trough where they are widely distributed throughout the Visean.

The thickness of the Upper Baytag sub-formation ranges from 100 to 350 meters. It is 100 to 190 meters in central areas and in the Onkazhinsk trough, and it increases to 250 to 350 meters on the southern slope of the West Tannu-Ola Range.

Its total thickness ranges from 225 meters

(Ekki-Ottug Creek) to 1,300 meters (Barshiin-Gol Creek).

### THE EKKI-OTTUG FORMATION $C_1^{ek}$

This formation corresponds to the Tebek formation of I.V. Kuznetsov and N.G. Popov, to the lower part of Z.A. Lebedeva's Dzharik formation, and to the $C^d{}_1$ formation of Ya.S. Zubrilin and A.M. Danilevich. It is developed in about the same areas as the Baytag, but is considerably thinner than the latter, because of a pre-Jurassic and chiefly of a recent erosion. The formation name is derived from the Ekki-Ottug Creek, a left tributary of Erbek River, where it is well exposed.

This formation is made up chiefly of lilac-red-brown, less commonly brown-gray and green, fine- to medium-grained, locally coarse-grained sandstone, with strictly subordinate ferruginous tuff and tuffite and very rare limestone and conglomerate. It is overlain by the Aktal formation which differs from it mainly in its green color. For this reason, its upper boundary is drawn at the first appearance of green beds.

Most common of the Ekki-Ottug sandstones are: 1) tuffaceous, polymictic, with a slightly altered volcanic binding matrix; they differ from similar Baytag rocks in their high iron content and in the practical absence of chloritization of their volcanic glass; 2) ferruginous, tuffitic, polymictic, mostly fine-grained, with an albitized volcanic matrix. The first type is developed mainly in Central Tuva and the Onkazhinsk trough; the second, primarily in the Aktal trough. Tuffaceous units of this formation carry tuff and tuffite with a preserved ash structure, finely sandy, albitized and ferruginous, locally only slightly siliceous and ferruginous.

This formation is marked by its lithologic consistency, both vertically and areally. One of its features is the preferential association of tuff and tuffite with its lower part. In northeast Central Tuva (along the left bank of Biy-Khem River and Kamennyy Klyuch Creek), the lower part of this formation carries thin beds of peculiar siliceous limestone containing bizarre inclusions of red chalcedony. No organic remains have been found in this formation, with the exception of occasional and undeterminable floral imprints.

Tentatively assigned to the Ekki-Ottug formation is the uppermost part of the Barshiin-Gol — Mooldykhem section, whose visible thickness is 125 meters, represented by alternating tuffite and sandstone, lilac-gray to dark lilac with greenish gray intercalations. Present in its upper part are vivid green tuffite and a gray limestone bed, 0.5 meter thick. Considering the general thickening of all formations to the southwest, toward the Barshiin-Gol, and also considering the lithology of this unit, it may be assumed that it represents the lowest or even the uppermost part of the Baytag formation, described above.[10]

The thickness of the Ekki-Ottug formation ranges from 110 to 290 meters, increasing generally from northeast to southwest.

### THE AKTAL FORMATION $C_1^{ak}$

This formation was first identified by I.V. Kuznetsov and N.G. Popov. Before that, the corresponding deposits were included by Ya.S. Zubrilin and A.M. Danilevich in the upper (gray) part of the $C_{1r}$ formation. Because of pre-Jurassic and later erosions, this formation is appreciably thinner throughout the Tuva area than the underlying lower Carboniferous sequences. Its type section is located near settlement Ak-Tal.

The Aktal formation is made up of sandstone of various shades of green (generally drab green) to red, coarse-grained, with subordinate dark gray, less commonly green tuff and tuffite, locally (Ekki-Ottug Creek) alternating with dark gray limestone. There are occasional gravel beds. The formation is overlain by either Jurassic or Carboniferous-Permian beds (Onkazhinsk formation), with stratigraphic unconformity, and with a conglomerate at its base.

The Aktal sandstone differs from those below in its definitely polymictic composition, coarse grain, and the predominance of the clastic fraction over the cementing component.

The most common tuffaceous rocks in the Aktal formation are albitized tuffs, locally containing some organic material. There are occasional siliceous and chloritic tuffs and tuffites, and issolated occurrences of ferruginous tuff.

The two most complete sections of this formation, at Ak-Tal and Kamennyy Klyuch Creek, demonstrate fairly well that its lower part is made up of coarse clastics while the upper part consists mostly of dark gray tuffaceous units. No substantial changes in the Aktal formation have been found in the Tuva area, and no identifiable organic remains.

In the Aktal and Onkazhinsk troughs, where

[10] This unit, as mentioned before, was designated as the individual Mooldykhemskaya formation, by I.V. Kuznetsov and others.

the Aktal formation is overlain by the Onkazhinsk, its thickness is about 130 meters and 230 meters, respectively. In all exposures of Central Tuva, where this formation is overlain by the Jurassic, its thickness ranges from 20 to 135 meters.

The above-described differentiation of the lower Carboniferous of Tuva is based mostly on lithology. Paleontologic data were strictly subordinate, not only because of their scarcity but also because of the inadequate paleontologic study. It is therefore necessary to organize the collection and identification of organic remains, first of all macroflora, spores and ichthyofauna.

We have determined that the colors of lower Carboniferous deposits in Tuva, unlike their lithologic features, cannot be used as a basis of stratigraphic differentiation, inasmuch as they are subject to substantial lateral changes. The regularities of these changes are not well known. At the present time, it can only be stated positively that green rocks tend to become mostly red, from northeast Central Tuva to the southwest, toward the south slope of the West Tannu-Ola Range. In so far as the color of rocks may be a useful criterion in large-scale mapping and other prospecting work, it is expedient to study the regularities in its change in the lower Carboniferous deposits in Tuva.

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The Union Geologic Exploration Office,
Main Administration for the Gas Industry
at the Council of Ministers, U.S.S.R.
Moscow

Received June 6, 1958

# NEW DATA ON PRECAMBRIAN (SINIAN) AND LOWER PALEOZOIC DEPOSITS IN THE WESTERN PART OF THE KIRGHIZ RANGE (NORTHERN TYAN'-SHAN')[1]

by

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New data are cited on the stratigraphy of the western terminus of the Kirghiz Range (Tyan'-Shan') where Cambrian deposits were not known previously. The author's conclusions are based on the presence of a Middle and Upper Cambrian fauna in the Kirghiz Range and on a study of the standard section embracing the upper part of the metamorphic complex (tentatively Sinian), most of the Cambrian, and lower half of the Ordovician. The author's data confirm the prevailing opinion on the consistency of lower Paleozoic sections within the North Tyan'-Shan' structural zone.

Starting from a comparison of sections of the Kirgiz Range and the Chatkalo-Narynsk zone, the author gives his interpretation of the distribution of the geosynclinal formations of the lower Paleozoic.

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## INTRODUCTORY REMARKS

The original stratigraphic classification of ancient formations in the Kirghiz Range was worked out by V.A. Nikolayev, in 1928 [11, 12]. He described a thick section of Precambrian metamorphics in a large brachianticlinal structure which he named the Makbal' anticline. The nucleus of this structure is made up of quartzite, garnet mica schist, marble, and amphibolite of the Makbal, Nel'din, and Kaindin formations, tentatively assigned to the lower Proterozoic. The limbs are formed by phyllite, crystalline limestone, and quartzite of the Kenkol' formation which he assigned to the upper Proterozoic—Lower Cambrian. This ancient sequence is capped by unmetamorphosed sandstone and shale carrying an Ordovician fauna (the Lingula and the Karasay formations).

Nothing essentially new has been added to V.A. Nikolayev's classification since its publication, although most of the Tyan'-Shan' geologists shared the opinion that Cambrian as well as the Ordovician deposits are present in the Kirghiz Range. Nevertheless, the age of rocks often designated as Cambrian has never been substantiated by fossil fauna. Only as a result of recent geologic surveying in Northwestern Tyan'-Shan' by the All-Union Aero-Geological Trust (VAGT), were new data obtained which made it possible to complete the lower Paleozoic stratigraphic column for the Kirghiz Range. This became feasible after the author discovered, in 1957, localities in which rocks carried a Middle and Upper Cambrian fauna, near the axial part of the range, at the Chungur and Kokdunen passes, southwest of Lugovaya Station. A standard section was also established there, including the following complexes separated from each other by angular unconformities:

1. regionally metamorphosed terrigenous clastic and carbonate rocks of the Uchkoshoy formation whose age is tentatively assumed to be Sinian; this formation is stratigraphically higher than the Kenkol';

2. a spilite formation, tentatively Lower Cambrian;

3. a volcanic sedimentary Middle and Upper Cambrian formation;

4. Ordovician shale and sandstone.

The structure of this area, on the northern limb of the Makbal' anticlinorium, is very simple. All of the above formations are involved in the structure of two large linked linear folds, the Kokdunen anticline and the Kotudzhan syncline, trending northwest (Fig. 1). The first is formed by the Sinian Uchkoshoy

[1] Novyye dannyye o dokembriyskikh (Siniyskikh) i nizhnepaleozoyskikh otlozheniyakh zapadnoy chasti Kirgizskogo khrebta.

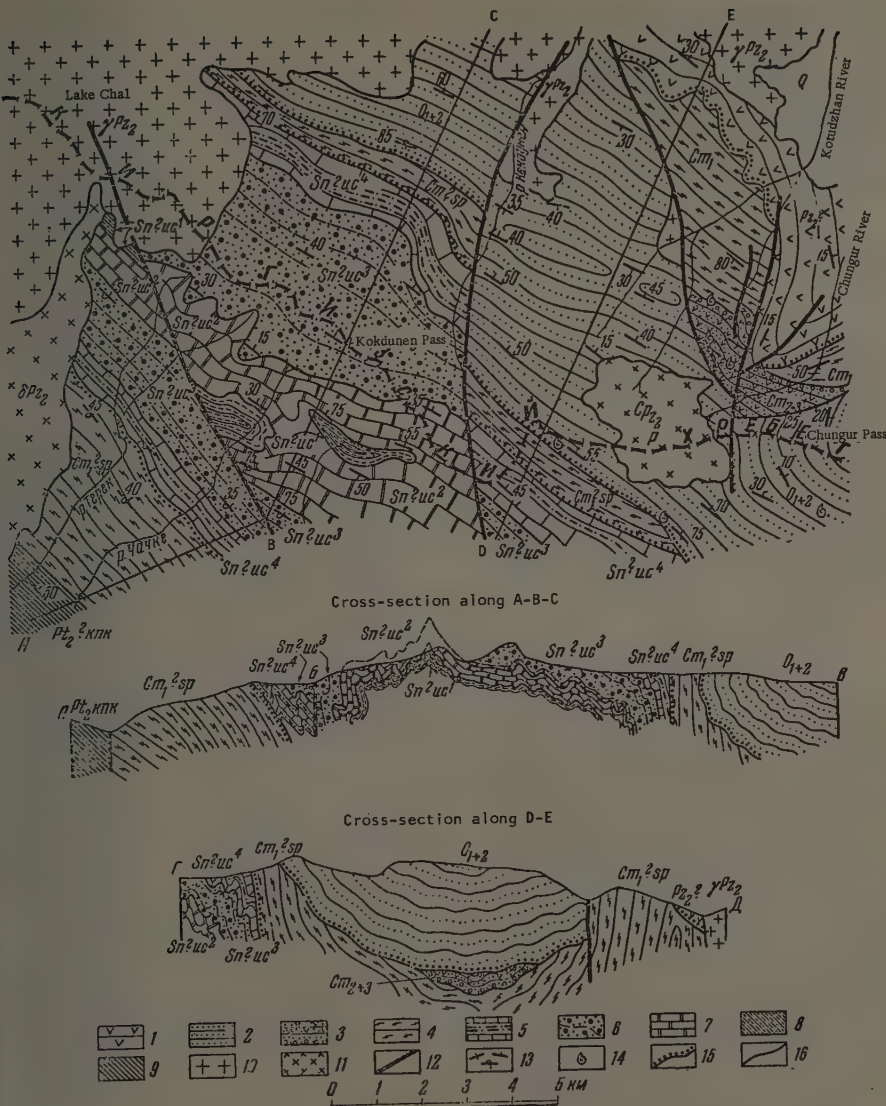


FIGURE 1. Generalized geologic map of the Chungur and Kokdunen passes area (Kirghiz Range). Compiled by A.F. Stepanenko.

1 -- volcanic sequence, presumably middle Paleozoic; 2 -- Lower-Middle Ordovician terrigenous rocks; 3 -- Middle and Upper Cambrian volcanic sedimentary rocks; 4 -- spilite formation, presumably Lower Cambrian; the Uchkoshoy formation, presumably Sinian; 5 -- limestone, phyllitic metashale, sandstone, quartzite; 6 -- phyllitic metashale, sandstone and quartzite; 7 -- limestone; 8 -- carbonaceous metashale; 9 -- the Kenkol' formation, presumably upper Proterozoic-Sinian; 10 -- middle Paleozoic granite; 11 -- middle Paleozoic diorite; 12 -- faults; 13 -- elements of rock occurrence; 14 -- localities of lower Paleozoic fauna; 15 -- stratigraphically unconformably contacts; 16 -- normal stratigraphic and intrusive contacts.

formation; the second, by Upper and Middle Cambrain and Ordovician deposits. The limbs of these structures are formed by Lower Cambrian spilite. The Kokdunen anticlinal section is marked by a gently dipping, very broad arch decidedly box-like in form, and by the nearly vertical and the overturned steep southwestern limb. Thus the anticline as a whole has a fan-shaped form; it is asymmetrical and overturned to the southwest.

The Kotudzhan syncline presents a broad and straight fold with steep, locally vertical limbs and a gently dipping central part.

The Kokdunen anticline borders in the southwest on another synclinal fold, brought in a close contact with the Proterozoic nucleus of the Makbal' anticlinorium by a major fault, and overturned to the southwest.

The main complicating elements of these folds are two lateral faults which break them up into three blocks. The magnitude of lateral displacement along these faults is 3 kilometers. The northeastern limb and a portion of the nucleus of the Kotudzhan syncline are torn by a steep thrust.

## Sinian Complex
## The Uchkoshoy Formation

Metamorphic rocks assigned to the Uchkoshoy formation are involved in the structure of the Kokdunen anticline nucleus. The considerable area of these outcrops lies within a broad contact halo of large intrusive massifs of granite and diorite, where the Uchkoshoy rocks have undergone considerable alteration expressed in the transformation of terrigenous rocks into andalusite-cordierite-biotite schist, and of limestone to marble with tremolite and diopside. The intensity of felsitization in the enclosing rocks decreases rapidly away from the intrusive contacts; on the Kokdunen pass meridian, in the northern limb of the anticline of that name, the rocks carry no perceptible evidence of contact effect with the intrusive body. It is here that the best sections of the metamorphic complex are exposed.

Four sequences have been identified in the section by their lithology; because of their different color they are readily traceable in the field and on aerial photographs.

1. Exposed in the nucleus of the Kokdunen anticline is a sequence of carbonaceous metashales (Sn?uc$^1$), mostly black, stained, strongly schistose, consisting chiefly of graphitic carbonaceous material with a small addition of clastic quartz and sericite. A bed of black carbonaceous, thin-banded crystalline limestone is present in the top. The visible thickness of this sequence is as great as 170 meters.

2. Resting conformably on that, there are light gray, gray, and dark gray finely crystalline massive and thin-banded limestones (Sn?uc$^2$). The banding is connected with an uneven distribution of carbonaceous matter. The massive varieties usually carry grains of quartz sand and silt. Commonly present in limestones are intercalations and rounded to amorphous nodules of gray chert. Very widely developed are lentils, beds, and pockets of syngenetic breccia-like limestones cemented by a carbonate material with a carbonaceous admixture. The thickness of limestones, south of the Kokdunen pass, is about 300 meters.

3. Resting with a gradual transition on the limestones are phyllitic metashale, sandstone, and quartzite (Sn?uc$^3$). Predominant in the lower part are phyllite-like quartz to plagioclase-quartz sandstone, siltstone, and quartzite. These sandstones are gray, dark to brown-gray, massive to thin-bedded, with a blasto-psammitic structure, consisting of unevenly rounded, poorly-sorted quartz grains with addition of plagioclase grains (oligoclase). The pelitic cement in the sandstone has been altered to a microlepidoblastic aggregate of sub-parallel scales of chlorite and sericite. In dark varieties, this aggregate is greatly enriched in carbonaceous matter. A definite schistose structure is present in both the orientation of clastic grains and in the orientation of chlorite and sericite scales. The quartzite is characterized by a granoblastic structure and consists of isometric quartz grains with serrate edges; present among them are occasional rounded grains of tourmaline and zircon. Phyllitic metashales predominate in the upper intervals. They are clearly schistose rocks, dark gray with a typical silky luster; they consist of a lepidoblastic aggregate of uniformly oriented scales of chlorite and sericite with considerable addition of carbonaceous particles. Enmeshed among them are grains of quartz silt, elongated parallel to the schistosity. The metashales are in a gradual transitional contact with phyllitic silt and sandstone. Beds and lenses of dark gray to gray, thin-banded recrystallized limestones are strictly subordinate. This sequence is 600 to 700 meters thick.

4. The Uchkoshoy section culminates in an uneven alternation of beds (0.5 to 15 meters thick) of limestone, phyllitic metashale, sandstone, and quartzite (Sn?uc$^4$). The limestone accounts for no less than 50% of the entire section; externally, it does not differ from the typical varieties of limestone. It is bituminous, with a characteristic odor on a fresh

break. Fairly common are beds of breccia-like limestone. The visible thickness of the metashale-sandstone-limestone sequence reaches 250 to 300 meters.

Thus the total thickness of the Uchkoshoy section is 1,400 meters.

A similar section has been observed in the southern limb of the Kokdunen anticline, in the headwaters of Terek River and far outside the area under study, north of the Makbel' pass. No fossil fauna has been found here, but the limestones locally carry indistinct organic remains similar to silicified calcareous algae. There are certain conspicuous features (phyllitization and cleavage in shale and sandstone; minute drag folds complicating the numerous larger folds) associated exclusivel with Precambrian metamorphics and not duplicated in overlying lower Paleozoic formations. The similarity in section (carbonate and terrigenous facies, free of volcanic material) and in the structure of the Kenkol' and Uchkoshoy formations also should be taken into consideration. However, despite their great similarity, the two are not stratigraphic equivalents. This is because the most complete Kenkol' section, immediately southwest of this area, does not contain the analogues of the Uchkoshoy section; in addition, the metamorphism in the Uchkoshoy rocks is less intensive. Metamorphic rocks cropping out in the nucleus of the Kokdunen anticline are undoubtedly higher stratigraphically than the Kenkol' formation. At the same time, the Uchkoshoy formation is older than the spilite which is assigned tentatively to the Lower Cambrian, because the latter formation rests on it with angular unconformity.

Thus, from its stratigraphic position, the Uchkoshoy formation belongs either to the uppermost Precambrian (Sinian) or to the very base of the Lower Cambrian. Considering that in a number of structural features the Uchkoshoy formation is much closer to the upper Proterozoic Kenkol' formation than to volcanic sedimentary Cambrian rocks, it may be assigned tentatively to the Sinian.

## Lower Cambrian
## The Spilite Formation

The limbs of the Kokdunen and the Chungur structures are formed by volcanic rocks of a spilite formation resting upon the Uchkoshoy with a major regional unconformity. Basal conglomerates are absent at the base of the spilite formation. Resting directly upon the strongly disturbed crystalline limestone, phyllitic metashale, and sandstone, which cap the Uchkoshoy formation, are massive spilites locally carrying at their base unsorted angular fragments of the underlying rocks. This unconformity cannot be seen as a rule in the small exposures exhibiting the stratigraphic contact of the spilite and the Uchkoshoy formations; an impression is often created therefore that their contact is conformable. However, a comparison of the nature of the tectonics and the degree of regional metamorphism affecting these two formations always reveals the great difference between them.

The spilite section is inconsistent in facies. In the area of the Kokdunen and Chungur passes, it consists mostly of basic extrusives (spilite and albitic diabase) and to a smaller extent of their tuffs (tuffaceous lavas and breccias). Typical of the middle and upper parts of the sections are flows of amygdaloidal lavas of a spilitic composition. The extrusives generally preserve their spherical to pillow texture. The rocks are dark, drab green to blue-green, brought about by autometamorphism resulting in the development of chlorite, epidote, and calcite. Pyroxene of the porphyry inclusions in extrusives is uralitized, while plagioclase is decomposed to form chlorite and sossurite. Strictly subordinate in the spilite section are inconsistent beds and lenses of green-gray, lilac-gray, and dark gray jasper and banded siliceous schist. At the top of the section, the amygdaloidal spilite locally carries thick (up to 150 meters) lenticular bodies of limestone, being replaced by extrusives. The thickness of this formation reaches 2,000 meters. The petrographic and textural features of its rocks suggest their association with a spilite formation characterized by submarine outflows of basaltic lava.

On the right bank of Makbal' River, to the west and outside the area under study, the spilite section has a different aspect. Spilites predominate only in the middle part, while in the upper and lower parts they form isolated beds, 1 to 5 meters thick. Best developed in the lower third of the section are assorted siliceous rocks: jaspers and greenish-gray, white, black, and sealing-wax red siliceous metashales. At the base of the formation, there is an inconsistent horizon of greenish gray polymictic (graywacke) sandstone, alternating with beds of green, less commonly red-brown shale. The upper part of the section is made up chiefly of various volcanic breccias and agglomeratic tuffs. In the very top of visible layers, these rocks are replaced by motley jasper and siliceous shale and schist interbedded with green-gray polymictic sandstone and carrying typically small lenses of massive gray limestone. The visible thickness of this formation is 1,400 to 1,500 m. The upper part of the section is cut off by a major fault which separates the spilite section from the Proterozoic rocks of the Makbal' anticline.

Very typical of the spilite formation is the presence of intrusives represented by dike-like bodies of diallage gabbro — a derivative of the basic magma which never reached the surface and solidified at some depth.

No organic remains other than radiolaria and sponge spicules in jasper have been found in the spilite formations; therefore, its age has been determined in an indirect way.

In the composition of its component rocks, the spilite formation is close to the overlying and paleontologically studied Middle and Upper Cambrian volcanic and sedimentary rocks. The volcanic sequence on the whole is quite different from Precambrian formations, in the slight regional metamorphism of its sedimentary rocks, similar to that of the Ordovician, and in the general morphological similarity of its folded structures, different from Precambrian structures. All these facts suggest a major stratigraphic significance for the spilite-Uchkoshoy contact which separates the Precambrian and lower Paleozoic complexes.

## Middle and Upper Cambrian
## The Volcanic Sedimentary Sequence

Outcrops of faunally determined Middle and Upper Cambrian form a small area at the headwaters of Chungur and Kotudzhan Rivers, north of the Chungur pass. Here, they are represented by a comparatively thin sequence of volcanic and sedimentary rocks. Good exposures and the slight disturbance of the rocks afford a detailed section exposing this volcanic sedimentary interval and give an idea of its stratigraphic relationship with the underlying and overlying units. The position of Middle and Upper Cambrian beds in the general tectonic framework of the area is well demonstrated.

It appears that the nucleus and a segment of the northeastern limb of the Kotudzhan syncline are brought up on a major thrust, trending north-northwest; as a result, the body of Ordovician rocks forming the nucleus of the fold has been almost completely removed by erosion, with only a small remnant left behind. This has uncovered the deposits underlying the Ordovician terrigenous beds in the Kotudzhan syncline, which are Middle and Upper Cambrian.

In this area, the volcanic sedimentary sequence forms a simple synclinal fold with the axis trending northwest. Its southern limb and core are cut off by an overthrust. In the north, this formation rests with an erosional and slightly angular contact on the Lower Cambrian spilite formation. Dips in the northern limb are steep, locally almost vertical; they flatten toward the axis and do not exceed 45° at the contact with the Ordovician remnant. It may be assumed that this zone of Middle and Upper Cambrian rocks in olved in the structure of the Kotudzhan syncline continues northwest and southeast under the cover of transgressive Ordovician rocks.

No Middle and Upper Cambrian volcanic sedimentary outcrops have been observed in the limb of the Kotudzhan syncline where the Ordovician rests directly on the spilite formation.

The Middle and Upper Cambrian volcanic sedimentary section in this area is represented by the following rocks:

1. Resting with a slight erosional and angular unconformity upon the green amygdaloidal spilite with limestone lenses, at the top of the spilite formation, is the basal unit of a volcanic sedimentary formation. This section begins with a bed of dark to green-gray massive rocks consisting of unsorted rubble and angular chunks (up to one meter) of the underlying spilite and diabase. The fragments are cemented with a very small amount of carbonate material. This bed is 5 meters thick.

2. Going upward, the importance of the carbonate cement increases until the rocks become massive light to green-gray limestone with rubble and chunks of spilite, diabase, and jasper. The amount of fragments is very inconsistent. Locally the rocks exhibit the features of a basal breccia. This bed of limestone with the addition of clastics is 20 meters thick. It is overlain conformably by clastic and carbonate rocks.

3. The latter unit begins with a bed of limestone 5 meters thick, gray to dark gray, fine-grained, massive, locally crumbled. A small inconspicuous lentil of limestone, one meter above the base, contains poorly preserved remains of trilobites — *Kootenia granulata*, *Chondranomocare kirgizensis*, and *Kuteniella* (the Kutudzhan faunal unit).

4. Alternating, inconsistent beds and lenses of sandstone and sand-gravel-pebble conglomerate. The beds are 1 to 5 meters thick. The sandstone, which predominates in this interval, is green-gray, unstratified, thickly platy, fine- to medium-grained, less commonly coarse-grained, polymictic. Predominating among the fragments are more or less rounded, poorly sorted grains of the spilite formation rocks: diabase, spilite, chloritized glass, siliceous rocks, and limestone. The cement is carbonate, of a basal porous type. The sand-gravel-pebble conglomerates have the same composition as the fragments and

the same cement as the sandstone. Present in the conglomerate, along with unsorted and unevenly rounded fragments of the spilite formation, are rubble and pebbles of limestone similar to those described from the Kotudzhan faunal unit.

Present among sandstone in the middle part of this unit is a two meter bed of massive gray limestone. This unit is 25 meters thick.

5. It is overlain conformably by greenish gray, thick, platy polymictic sandstone, fine- to medium-grained, similar to those described from unit 4. Typical are varieties of rocks where the amount of fragments and of carbonate cement is about the same. Toward the base, sandstone carries small lenses of gray sandy limestone. This sequence is capped by a one meter thick bed of dark gray coarse-grained sandstone and pebbles with a carbonate cement. This unit is 16 meters thick.

6. It is overlain with a sharp contact by thick and externally monotonous tuffoid rocks, green, unevenly to thinly stratified. Intercalations of tuffite are seen under the microscope (clastic grains less than 0.1 millimeter) and tuffaceous sandstone (grain-size 0.1 to 0.2 millimeter). The fragments, usually sharply angular, are of jasper rocks, spilite, decomposed plagioclase, and quartz. The cement is tuffaceous, intensively replaced by chlorite and calcite. Toward the top, the tuffites are replaced by thin-banded finely to medium-crystalline lithocrystalloclastic tuff. The fragments in them are angular, represented by sossuritic plagioclase, seldom by quartz. The cement is ash, recrystallized and replaced by chlorite and epidote. Present among the tuffs are isolated lenses of white marble limestone. This unit is 250 to 300 meters thick.

7. Resting with a sharp contact on the green tuffs, are stratified, dense, strongly altered tuffites, of a motley (red-brown to green) color caused by bed-by-bed hematitization and epidotization. Thickness, 10 meters.

8. Micro- to thinly-stratified, very dense chloritic and carbonate green-gray tuffite, 20 meters thick.

9. A haphazard alternation of thin tuffite and tuffaceous fine-grained sandstone, green to red-brown. The clastic grains are mostly of plagioclase and quartz cemented by recrystallized ash. Present among the tuffites are thin lentils of light-gray sandy limestone. The tuffoid rocks (unit 8), to the west, are facially replaced by drab brown to green lithocrystalloclastic fine- to medium-grained tuffs of a mixed (intermediate and basic) composition. Fragments in tuff are of porphyrite, spilite, jasper, and plagioclase, with a tuffaceous cement. Thickness, 30 meters.

10. An inconsistent bed of amygdaloidal plagioclase-pyroxene porphyrite, dark, drab-green, massive. Present in the inclusions are crystals of fully decomposed (carbonatized and sossuritized) plagioclase and chloritic augite. The groundmass is hyalopilitic, consisting of variously oriented microliths of plagioclase and pyroxene. They are immersed in a cyrstalline vitreous matrix with intensively developed chlorite, leucoxene, carbonates, and ore minerals. In their upper part, the porphyrites locally change to coarse clastic tuff and folcanic breccia consisting chiefly of fragments of the underlying porphyrite, tuff, and limestone. Thickness, 3.5 to 10 meters.

11. Resting conformably on the previously described sequence is the Chungur faunal unit consisting of microgranular light to dark gray massive limestone with numerous lenses of breccia-like limestone and shale. Oolitic limestone is locally important. Remains of trilobites, lingulas, and brachiopods Pseudoagnostus, Aphelaspis, Billingsella, have been collected from three exposures, in dark gray limestone and sedimentary breccia in the lower third of the bed. Thickness, 3 to 6 meters.

12. A bed of gray massive siliceous, jasper-like rocks with radiolaria remains. Thickness, 1 meter.

13. An inconsistent bed of tuffaceous breccia of unsorted, semi-rounded to angular chunks and rubble of the underlying limestone, chert, and porphyrite, with a tuffaceous cement. Total thickness up to 25 meters. To the west, they are replaced facially by tuff and tuffite.

14. A bed of red-brown, fine- to medium-grained, vitrocrystalloclastic tuff. Thickness, 20 meters.

15. Thin, haphazardly alternating green-gray tuffite, tuffaceous sandstone, and light-gray limestone. Visible thickness, 50 meters.

16. Resting on these rocks with an erosional break followed by a basal conglomerate up to 1 meter thick, are polymictic Ordovician sandstones. Their visible thickness is only 50 meters. The higher Ordovician units are cut off here by a fault.

The total thickness of this Middle and Upper Cambrian section is not over 550 meters.

The trilobite fauna of the Kotudzhan (unit 3) and Chungur (unit 11) units was studied and determined by N.V. Pokrovskaya. As a result,

the following species have been identified: Kootenia granulata Pokr. (ms); Chondranomocare kirgizensis sp. nov.; Kooteniella cf. sayanica Pokr. (ms); Solenopleura cf. recta N. Tchern.; Elrathia sp.; Hypagnostus parvifrons (Linnars).

The age of the Kotudzhan faunal unit has been determined by N.V. Pokrovskaya, from the following data.

Species Kootenia granulata Pokr. and Kooteniella sayanica Pokr. are known from the Eastern and Western Sayans, Kurnetsk Alatau, and the Siberian platform, where they occur in the Middle Cambrian Amgin stage.

Genus Chondranomocare Palet., in the Kuznetsk Alatau, Western Sayan, and Siberian platform, is typical only of the Amgin stage (particularly its lower part). In the collection, it is represented by a new species.

Species Solenopleura recta N. Tchern is associated with the Amgin stage, in the Siberian platform, but it strays occasionally in the lower part of the Maysk stage.

Species Hypagnostus parvifrons (linnars) is present almost everywhere. In Sweden, Norway, Island of Bornholm, England, North America, it occurs in the Middle Cambrian (Paradoxides hicksi and Paradoxides davidis beds); in the U.S.S.R., it often occurs in the Amgin stage and less frequently in the base of the Maysk stage.

Genus Elrathia sp. is distributed almost throughout the entire Middle Cambrian section. Its specific determination is impossible because of its generally poor state of preservation.

Thus, species occurring in the Kotudzhan faunal unit suggest a Middle Cambrian age. Apparently it is not younger than the Paradoxides hicksi - Tomagnostus fissus zone. Kooteniella Lerm. does not persist beyond this boundary.

Kootenia granulata, Chondranomocare kirgizensis, and Kooteniella cf. sayanica, present in the Kotudzhan fauna, occur in the Siberian platform, Kuznetsk Alatau, and Eastern and Western Sayans, usually in association with Erbia sibirica, Chondragroulo, Olenoids, and Ptarmigania, i.e., an early Cambrian assemblage known from the Agyrek unit (Central Kazakhstan). This makes it possible to regard the Kotudzhan unit of the Kirghuz Range as an age equivalent of the Agyrek unit.

N.V. Pokrovskaya succeeded in identifying the following forms from the Chungur unit: trilobites Pseudoagnostus cf. pseudocyclopyge Ivsch., Aphelapsis boshchekulensis Ivsch., A. kirgizensis sp. nov.; brachiopods Billingsella sp. Acrotreta sp., Lingulella sp. A study of this fauna not only confirmed the Upper Cambrian age of the Chungur unit, but also pinpointed its position within the Upper Cambrian.

Aphelaspis Ress. is an exclusively Upper Cambrian genus. In North America, it occurs in the Nolichucky formation, the Dresbach stage; in Central Kazakhstan, in the Kuyandin formation, the lower half of the Upper Cambrain. Two species have been identified in the collection: one new and another, the Aphelapsis boshchekulensis Ivsch., described by N.K. Ivshin from the Kuyandin unit, Central Kazakhstan.

Pseudoagnostus Whit. is primarily an Upper Cambrian genus known from North America, England, Sweden, Norway, Australia, China, Manchuria, Korea, Kazakhstan, Salair, the Siberian platform, etc. In our collection, it has been identified as Ps. cf. pseudocyclopyge Ivsch., a form close to the leading species from the lower Upper Cambrian Kuyandin unit of Central Kazakhstan (Tortkuduk formation). No less typical is the presence in the Kuyandin unit, of the Billingsella type brachiopods, also occurring in the Chungur unit. Consequently, the Chungur unit belongs to the lower half of the Upper Cambrian (Dresbach of the American biostratigraphic scale).

## Lower - Middle Ordovician Terrigenous Sequence

Exposed in the headwaters of Kokdunen and Kotudzhan are thick terrigenous Ordovician rocks. Here, they form a simple symmetrical syncline trending northwest. The limbs of this syncline are steep, locally almost vertical, while the trough is broad and gently dipping. The generally monoclinal position of beds in the limbs is often broken by a step-like structure connected with a change in the angle of dip.

Ordovician rocks rest transgressively, underlain by basal conglomerate, on all three formations described above. Their most extensive contact is with the spilite formation, in the southwestern limb of the Kotudzhan syncline. The angular unconformity between Lower Cambrian and Ordovician beds is not directly observable in outcrops, but becomes obvious in the course of mapping.

The Ordovician section is well exposed in this area and has been observed in several traverses across the southwestern limb of the Kotudzhan syncline. Its stratigraphic components are as follows, reading upward:

1. Basal conglomerate consisting of rubble, pebbles, boulders, and chunks of diabase, spilite, and occasional jasper from the underlying spilite formation. A similar close relation between the petrographic composition of fragments and pebbles in the basal beds with the underlying rocks, where the Ordovician rests upon Upper Cambrian and Sinian rocks, suggests that the material has been transported only a short distance. The conglomerate cement is areno-argillaceous. The basal conglomerates are 20 to 40 meters thick, locally wedging out.

2. Alternating inconsistent beds, intercalations, and lenses of green shale and fine-grained polymictic sandstone. The relationship between these varieties changes sharply, throughout the area. A five meter bed of pebble conglomerate with a carbonate cement has been observed 30 meters above the base. The pebbles are of the spilite and Uchkoshoy rocks. The conglomerate carries small isolated lenses of white to greenish-gray limestone which yielded at two points remains of small brachiopods, gastropods, orthoceratites and crinoid segments. This member is 50 to 80 meters thick.

3. Very motley and inconsistent alternation of red-brown, green, and lilac-colored shale, sandstone and silt with occasional beds of banded siliceous shale and black carbonaceous shale. Southwest of the Chungur Pass, these rocks are almost fully replaced by pebble conglomerates similar to those from unit 2. They also carry lenses of limestone with a fauna of small brachiopods. This horizon is 100 to 130 meters thick.

4. A very inconsistent unit facially, of alternating beds and lenses of sandstone, silty shale, and conglomerate. The latter usually are subordinate and do not occur in extensive beds. Only in isolated areas does the conglomerate predominate in the section. They are made up of small- to medium-size pebbles, massive, greenish gray. The pebbles are poorly sorted, well-rounded, consisting chiefly of rocks from the spilite and Uchkoshoy formations, also of gabbro from massifs which cut the spilite formation in the western part of the Kirghiz Range. The conglomerate cement is areno-argillaceous. Sandstone alternating with the conglomerate has a similar composition of clastic grains, except for a considerable amount of quartz and plagioclase. The grains are angular and ill-sorted. The cement is silty argillaceous. The silt and silty shale, interbedded with the sandstone, are connected with them by gradual transitions. This unit is about 250 meters thick.

5. Upward, the conglomerate disappears gradually giving place to a thick sequence of alternating polymictic fine-grained sandstone, silt, and silty shale, greenish to dark gray, either in unevenly thin (0.55 to 5 centimeters) or rhythmic, flysch-like beds. This rather monotonous section is only occasionally broken by isolated beds, from a few to 30 meters thick, of massive coarse-grained polymictic to tuffaceous sandstone and volcanic breccia. Present in the lower part of the section, southeast of the Chungur Pass is an inconsistent bed of light gray siliceous limestone with poorly preserved remains of trilobites and orthoceratites. This unit is 2 meters thick. The entire sequence is 2,000 to 2,200 meters thick.

Thus the overall thickness of Ordovician deposits is over 2,500 meters.

The brachiopod fauna (unit 2) was preliminarily studied by O.N. Andreyeva who identified Orthidae, <u>Camarella</u> sp., and <u>Strophomena</u> sp. Among gastropods and orthoceratites from unit 2, V.A. Vostokova identified <u>Lesucurilla</u> sp., and Z.G. Balashov identified <u>Pictetoceras</u> sp. Among trilobites from unit 5, Ye.A. Balashova identified <u>Onchonotus</u> sp. and <u>Nileus</u> aff. <u>scrutator</u> Billings, while Z.G. Balashov identified <u>Geisonoceras</u> sp. among the orthoceratites. In the opinion of all paleontologists, these forms indicate an Ordovician age for the enclosing rocks. According to Ye.A. Balashova, <u>Nileus</u> aff. <u>scrutator</u> is known from the Chazyan of North America, which corresponds to the lower part of the Middle Ordovician. In the Baltic region, this species is known from beds assigned to the Upper Arenig.

The stratigraphic position of the Ordovician terrigenous sequence is refined by correlating it with the structurally similar Lingula and Karasay formations from the west end of the Kirghiz Range. A fossil fauna, collected in different parts of these formations, suggests a Middle Ordovician age. Our sequence correlates well with the Lingula formation; for this reason, it may be tentatively assigned to the lower half of the Middle Ordovician. It is not impossible that its lower horizons might belong to the uppermost Lower Ordovician.

Resting on strongly disturbed Sinian and lower Paleozoic rocks, there is a volcanic complex of terrestrial liparite and andesite, up to 1,300 meters thick. It consists of extrusive and tuffaceous rocks, basic in its lower part; acid in the upper part. It is unconformably overlain by upper Visean — lower Namurian red conglomerate and sandstone. The areas of development of the volcanic and red complexes coincides with a major superimposed downwarping. The age of this volcanic complex is tentatively determined as middle Paleozoic (Devonian ?).

* * *

Recent works of many geologists [2, 4, 5, 6, 7] have demonstrated the unique similarity in the lower Paleozoic character of the Chatkal-Naryn structural facies zone, arc-like in plan, convex to the southwest, and extending from the Dzhezkazgan-Ulutau area in Central Kazakhstan to the sources of Naryn River in central Tyan'-Shan'. This zone is over 1,500 kilometers long.

It now becomes clear that a no less consistent but different lower Paleozoic section markes the North Tyan'-Shan' structural facies zone, extending parallel to the Chatkal-Naryn zone, from the Sarysu-Teniz watershed in Central Kazakhstan to the eastern terminus of the Terskey Alatau Range. The Kirghiz Range belongs to this zone.

In 1956 and 1956, lower Paleozoic sections, very similar in composition and general structure to rocks of the western Kirghiz Range section, were described by A.A. Bogdanov [1] for the Sarysu-Teniz watershed, and by V.G. Korolev for the eastern part of the Terskey-Alatau Range (see Fig. 2). An unquestionable similarity with the Kirghiz Range rocks also exists in the lower Paleozoic of northeastern Central Kazakhstan (the Seleta-Shiderta watershed), studied in detail by R.A. Borukayev [2]. Thus there are reasons to believe that uniform sedimentary conditions prevailed in the early Paleozoic, throughout an immensely long North Tyan'-Shan' zone. In the light of these data, it is possible to correlate lower Paleozoic sections of the North Tyan'-Shan' zone developed in isolated and distant areas.

Of great interest is the correlation of lower Paleozoic sections from the Chatkal-Naryn and North Tyan'-Shan' zones, which makes it possible to set up guiding indexes for the history of development of the Tyan'-Shan' geosynclinal province in the lower Paleozoic. For this purpose, we shall give a brief description of a lower Paleozoic section in the Chatkal headwater region, compiled by the author in 1955 and 1956 [15].

### Lower Cambrian

1. Greenish gray polymictic conglomerate and gravel, changing upward to siltstone, sandstone, and shale, with limestone lenses. The base of this sequence is not exposed. The visible thickness, 600 meters.

2. Tillite-like conglomerate, up to 300 meters thick.

3. A flysch-like alternation of gray to green-gray sandstone and shale. Thickness, 500 meters.

Total thickness of the Lower Cambrian is as great as 1,400 meters.

### Middle and Upper Cambrian

Dolomitic limestone locally replaced by shale, sandstone, and tillite-like conglomerate. The limestone carries remains of Lower and Upper Cambrian trilobites and algae. Thickness, 250 to 300 meters.

### Lower and Middle Ordovician

A facially inconsistent, diversified sequence of assorted siliceous rocks with subordinate limestone, dolomite, shale, sandstone, diabase, and tuff. The shale carries Lower and Middle Ordovician graptolites. Thickness, 800 meters.

### Upper Ordovician

Green-gray arkosic sandstone in the lower part, changing upward to flysch-like alternating graywacke sandstone and shale.

Thickness, over 1,000 meters. No evidence of regional stratigraphic breaks has been observed within this section.

A comparative study of lower Paleozoic sections from the Kirghiz and the Chatkal zones suggests the following stages of development in the Cambrian and Ordovician. It appears that in the early Cambrian to early Ordovician, these zones were involved in an uplift and a minor folding. The following hiatus was very brief (the Lower Cambrian spilite formation rests erosionally on the same interval of the Sinian Uchkoshoy formation). A general subsidence followed, and with it the accumulation of lower Paleozoic sediments of a geosynclinal type.

Different sedimentary sequences were deposited in different parts of this lower Paleozoic geosyncline, at the initial stage of subsidence. A thick sequence of coarse clastics was accumulated in the Chatkal zone, to the south; in the north, in the Kirghiz zone, the spilite formation was formed. Both formations (the spilitic and the areno-argillaceous) are typical of initial stages of the geosynclinal development and are closely related to each other. Spilite formations are generally related to the central parts of geosynclinal provinces, while the areno-argillaceous occur near the periphery.

At the close of the Lower Cambrian, weak folding movements were initiated in the area of the Kirghiz zone. Evidence of them also comes from the south, from those areas in

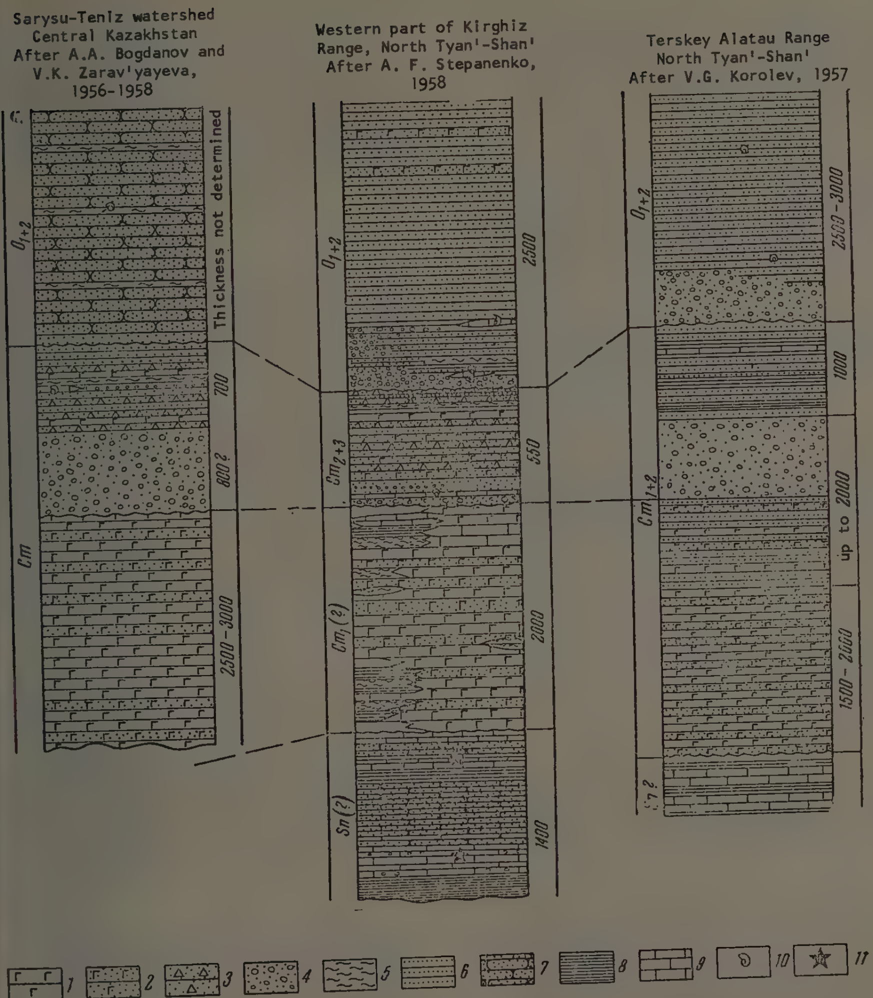


FIGURE 2. Correlation of lower Paleozoic section from the Kirghiz zone.

1 -- spilite, diabase, porphyrite; 2 -- their tuffs; 3 -- tuffite and tuffaceous sandstone; 4 -- conglomerate; 5 -- siliceous rocks; 6 -- flysch-like alternation of sandstone and shale; 7 -- quartz and arkose sandstone and quartzite; 8 -- shale, carbonaceous and phyllitic metashale; 9 -- limestone; 10 -- faunal remains; 11 -- stromatolithic remains.

the Chatkal zone, Middle and Upper Cambrian sections are made up fully of carbonate rocks. During the following subsidence, the sea transgression, proceeding apparently from the northeast, from Siberia by way of Central Kazakhstan, reached its maximum. The Middle and Upper Cambrian witnessed an accumulation in the Kirghiz zone, of thick limestone, tuffaceous sandstone, and tuffite, with subordinate siliceous rocks, porphyrite, and tuff. In the meantime, a rather thin sequence of limestone, locally replaced by shale, was deposited in the Chatkal zone.

A simultaneous Middle Cambrian marine transgression in Central Kazakhstan and the

Kirghiz and Chatkal zones is proven by the presence of a trilobite fauna, similar in specific composition, in basal Middle Cambrian beds. The minor thickness of Middle and Upper Cambrian deposits suggest a very slow rate of subsidence.

The subsequent history of the Kirghiz and Chatkal zones proceeded along somewhat different lines. A second phase of lower Paleozoic folding took place in the Kirghiz zone, apparently at the Cambrian-Ordovician boundary. It was followed, at the close of the Lower Ordovician, by a renewed subsidence of the geosyncline, marked by an intensification of oscillatory movements responsible for the deposition of thick Middle Ordovician terrigenous formations, often flysch-like (third stage of the geosynclinal development).

The beginning of the Upper Ordovician witnessed the onset of the third and the most intensive phase of the Kirghiz zone folding. In this process, Precambrian and lower Paleozoic sequences were simultaneously and intensively compressed into extended linear folds of the Makbal' anticlinorium. The Kirghiz zone became a folded belt standing out as a geanticline, during the middle and upper Paleozoic.

These data lead to the conclusion that the lower Paleozoic sedimentation stage in the Kirghiz zone presents a complete cycle of geosynclinal development.

No folding movement is reflected in the Ordovician history of the Chatkal zone. The marine transgression continued here in the Lower and Middle Ordovician, with a wide development of assorted siliceous rocks.

The situation changed rapidly at the Middle-Upper Ordovician boundary, with a thick flysch-like sequence deposited during the Upper Ordovician. The close of the Ordovician was marked by a slight revival of folding, after which sedimentation was not resumed till the Devonian. Apparently the formation of an Upper Ordovician flysch-like sequence in the Chatkal zone, as in the Kirghiz zone, constituted a final (third) stage of development of the Lower Paleozoic geosyncline. In the Kirghiz zone, however, the formation of this sequence started and ended earlier than in the Chatkal zone. The reason for such an advancement apparently was the fact that the Kirghiz zone was located in the interior of the Tyan'-Shan' geosyncline while the Chatkal zone corresponded to its peripheral part.

Interesting additional material is supplied by a lower Paleozoic section in the Talas Range which corresponds to the independent Talas-Karatau structural facies zone separating the Chatkal and Kirghiz zones.

The Talas Range lower Paleozoic was studied on many occasions and by different investigators (V.A. Nikolayev, P.L. Bezrukov, B.I. Smirnov, T.A. Konyuk, T.A. Dodonova, a group of geologists of the All-Union Aerogeologic Trust, and others). They have recognized the following sections:

### Lower Cambrian

A thick (over 2,500 meters) complex of sedimentary and igneous rocks is assigned to the Lower Cambrian. It begins with green-gray sandstone, silt, shale, and limestone, changing toward the middle to purple and lilac-colored silt and shale. At the top, there are motley ash tuff, tuffite, siliceous rocks, tuffaceous sandstone, and conglomerate. This complex correlates well with the Karoy formation from the Malyy Kara-Tau, with its typical Archaeocyathids.

### Middle Cambrian — Lower Ordovician

Resting on the Lower Cambrian, with an erosional contact, are massive, thick-bedded limestone and dolomite, up to 1,400 meters thick. They carry Middle Cambrian algae at their base (M.S. Potapova and Ye.A. Vorms, 1944); starting with 300 to 350 meters above that, there is a diversified fauna typical of the Tremadoc and Arenig Lower Ordovician stages (V.A. Nikolayev and T.A. Konyuk). These limestones are a stratigraphic equivalent of the Tamdin formation from Malyy Kara-Tau, better characterized faunally and assigned to Middle and Upper Cambrian and Lower Ordovician.

### Middle and Upper Ordovician

Separated from these limestones by an erosional break and a basal conglomerate, is a thick (about 5,000 meters ?) terrigenous sequence described in detail by A.A. Luyk [10]. It consists of polymictic and tuffaceous sandstone, tuff, and silt, with subordinate shale and limestone. Different parts of this section carry a fauna which suggests an Ordovician age (from the upper Lower to the lower Upper Ordovician).

A number of features here are conspicuous, some of which are peculiar to the Kirghiz type of section; others to the Chatkal.

A similarity between the Talas and Kirghiz section is in their character, with both being divided into three correlative formations. The stratigraphic extent of the correlative intervals

is about the same. A similarity between the differently built-up Talas and Chatkal sections is in the same composition of correlative sequences. There is a regular thinning of correlative intervals (particularly for the Middle and Upper Cambrian), going from the Kirghiz to the Talas zone, also in the Chatkal zone. These features make it possible to regard the Talas section as a transition between the Kirghiz and the Chatkal.

In summing up, the following conclusions can be set forth:

In the lower Paleozoic, the Kirghiz, Talas, and Chatkal (Chatkal-Naryn) structural facies zones were components of a major geosynclinal province embracing most of Tyan'-Shan' and Central Kazakhstan. The simple threefold series of geologic formations recognized in lower Paleozoic sections of each zone suggests a sedimentation pattern common for the entire geosynclinal province. Differences in the nature and thickness of the sections, together with a certain lack of synchronization in the formation of similar formations in different structural facies zones, were determined by their position in the Tyan'-Shan' — Central Kazakhstan lower Paleozoic province.

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Ministry of Geology
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Received January 19, 1959

# NEW DATA ON THE STRATIGRAPHY OF QUATERNARY DEPOSITS IN THE ALDAN RIVER VALLEY[1]

by

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Cenozoic deposits and the geomorphology of the Aldan River valley have long attracted the attention of many geologists. In 1912, V.N. Zverev first collected a large number of remains of Tertiary flora and Quaternary fauna [6] at an exposure along the Aldan lower course, known as Mamontova (Mammoth) Mountain. Much work in geomorphology of the central areas of Yakutiya was done by the Yakut Expedition, Academy of Sciences, U.S.S.R., in 1925, under the direction of A.A. Grigor'yev. This work was the basis for many important general conclusions reflected in the papers of V.A. Obruchev, A.N. Krishtofovich, and others.

A planned study of the Aldan basin did not begin until much later. In 1950-1951, geologic surveying was done there by the 4th Expedition of the All-Union Aerogeological Trust, under A.I. Olli. In 1953 to 1955, surveying was done by the 3rd Expedition of the same Trust, under G.F. Lungersgauzen. In 1957, a 1:1,000,000 geologic map was published (Sheet R-52), with a legend. Particularly valuable material for a correct interpretation of the regional structure was obtained from recent drilling by the Yakutsk Geological Administration in the lower Aldan area.

This paper is based on the author's study, 1954 to 1957, along the lower and middle course of the Aldan, and on the published data.

The Aldan River valley area under study, from its mouth to Maya River, is located within two large structural elements on the eastern periphery of the Siberian platform. Below the mouth of the Maya, the Aldan valley (middle course), which has a generally northeastern trend here, runs over the northern plunge of the Aldan shield and the south limb of the Vilyuy trough. This stretch is marked by the presence of erosion-deposition terraces, 11 to 160 meters high, and by its slight width, from several tens to several hundreds of meters. The alluvium is seldom thicker than 15 to 20 meters. From southeast to northwest, progressively younger Paleozoic and Mesozoic rocks are exposed at the base of the terraces.

In its lower course (from settlement Khandyga to the mouth), the Aldan changes its direction to latitudinal. Here, its valley runs within the socalled lower Aldan trough identified by R.A. Bidzhiyev, in 1956 [2]. This is a Cenozoic structure superimposed on the older fundamental structure of the Priverkhoyansk foredeep [9]. Jurassic and Cretaceous deposits line the sides of the lower Aldan trough, in narrow belts. Its central part is filled with thick Tertiary deposits exposed at the base of the Aldan terraces. Terraces here are somewhat different from those developed in the middle course. As a rule, high terraces (100 to 120 meters) on the Aldan left bank reach great widths (tens of kilometers), gradually changing to the watershed which presents a vast plain with above sea level elevations up to 400 or 500 meters. The peculiar aspect of this relief — fairly broken and yet monotonous with its thermal karst sinkholes, "alases," at times filled with water, and with glacial hills, "bulgunnyakhs" — has been brought about by processes related to the permafrost of the region. Left tributaries of the Aldan have low banks, a very sluggish flow, and relatively shallow valleys typical of plainland rivers. Younger terraces, 11 to 15 and 25 to 35 meters high, are widely developed.

The right bank of the Aldan fringes a hilly plain with widely developed glacial deposits, absent on the left bank. The Verkhoyan'ya front ranges reach here 900 to 1,000 meters. All right tributaries are typical mountain streams.

Closely related to the structural and morphologic features of the Aldan valley is the distribution and structure of its Cenozoic alluvial deposits. We shall consider those of the middle Aldan course first.

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[1] Novyye dannyye po stratigrafii chetvertichnykh otlozheniy doliny r. Aldana.

The oldest alluvial deposits are developed on high 100 to 160 meter terraces. They are represented by gray kaolinitic locally ferruginous, mixed-grain sands, with pebbles of resistant rocks (quartz, quartzite, chert). The thickness of these deposits seldom exceeds 1.5 meters. In analogy with the Lena and the high lower Aldan terraces, both fully characterized by a Tertiary flora, these deposits, too, may be assumed to be Tertiary [10]. This is confirmed by morphologic observations; present above settlement Khandyga, on the left bank of the Aldan, is a 100 to 130 meter terrace, almost continuous and traceable downstream, as far as Mamontovaya Mountain where its Tertiary age has been well substantiated.

Fairly widely developed deposits are associated with the 80 to 90 meter terraces. They are mostly sandy loams and sands, locally ferruginous, with pebbles; they are rather thin, from several centimeters to 2 meters thick. The terrace is traceable as a bench on either bank. The following section has been observed in a cut in the 90 meter terrace, on the left bank of the Aldan, 3 kilometers above the mouth of Allakh-Yun' River (reading downward):

$Q_3^{ped}$ 1. Soil, 0.3 to 0.4 meter;

$Q_1^{2al}$ 2. Yellow sand, fine-grained, kaolinite, with many pebbles of varying sizes (1 to 10 centimeters) and petrographic composition (with quartz and quartzite predominant); 1.5 to 1.6 meters thick.

$J_1$ 3. Base of the terrace — Lower Jurassic deposits, up to 88 meters.

Of interest is a section on the right bank of the Aldan, above settlement Okhotskiy Perevoz (Hunter's Ferry), where a 90 meter cliff exhibits the following sequence (from top to bottom):

$Q_3^{ped}$ 1. Soil, 0.3 to 0.5 meter;

$Q_3^{e-d}$ 2. Dark gray loam saturated with iron oxides; carrying plant remains; 1.5 to 2 meters;

$Q_1^{2al}$ 3. Pebble bed, ferruginous, cemented with sand; pebbles vary in size, degree of rounding, and lithology; boulders occur among the pebbles; up to 20 meters thick.

$J_1$ f. Lower Jurassic rocks at the base, 65 to 68 meters thick.

The 80 to 90 meter terrace deposits correlate well in the longitudinal cross-section (Fig. 1). They are unquestionably younger than the Tertiary and older than the lower terrace deposits. It is not impossible that the Eo-Pleistocene mammalian fauna found along the lower Aldan course comes from stratigraphic equivalents of the 80 to 90 meter terrace alluvium along the middle course.

Still younger deposits are associated with the 50 to 60 meter high terraces. They are represented by sandy loam, sand, and gravel. The pebbles are of various size and degree of rounding; they also differ lithologically (quartzite, schist, sandstone, granite, limestone, etc.) and are covered by manganese bloom. Similar gravel beds occur at the base of a lower 35 meter terrace where they are overlain by younger alluvium fully determined from its flora and mammalian fauna. Evidently these gravel beds are alluvium from an older, deeply eroded terrace. For that reason, also because of their relationship with the deposits of higher and lower terraces, the deposits of this terrace probably belong to the second half of the upper or to the beginning of the middle Pliocene ($Q_2^1$ - $Q_2^2$).[2]

Sandy loam, sand, and gravel beds associated with the 25 to 35 meter terraces are widely developed in the middle Aldan course. The following section is exposed in the face of a 35 meter terrace, on the left bank, 27 kilometers above Okhotskiy Perevoz:

$Q_3^{ped}$ 1. Soil, 0.4 meter thick;

$Q_3^{e-d}$ 2. Gray loam, dense, micaceous; 1.3 to 1.4 meters;

$Q_2^{2-3al}$ 3. Gray sandy loam, locally ferruginous, with conspicuous thin stratification; occasional plant remains (Larix dahurica cones); 1.5 to 2 meters.

$Q_2^{2-3al}$ 4. Gravel bed with sand; pebbles varying in their size, degree of rounding, and lithology (quartzite, chert, schist, porphyrite, etc.). It lies with sharp contact on a different gravel bed, with manganese bloom. This lower bed is similar to that in the higher 50 meter terrace on the left bank of the Aldan, below Ust-Maya; thickness, 10 to 12 meters.

$J_1$ 5. Lower Jurassic sandstone underlying the terrace; up to 20 meters.

A rodent fauna (Lemmus obensis, Ochotona hyperborea, etc.) was found in sandy loams (unit 3). From the same unit, Yu.M. Trofimov identified seeds of the following plants: Rubus idalus L., Viola sp., Carex sp. (three

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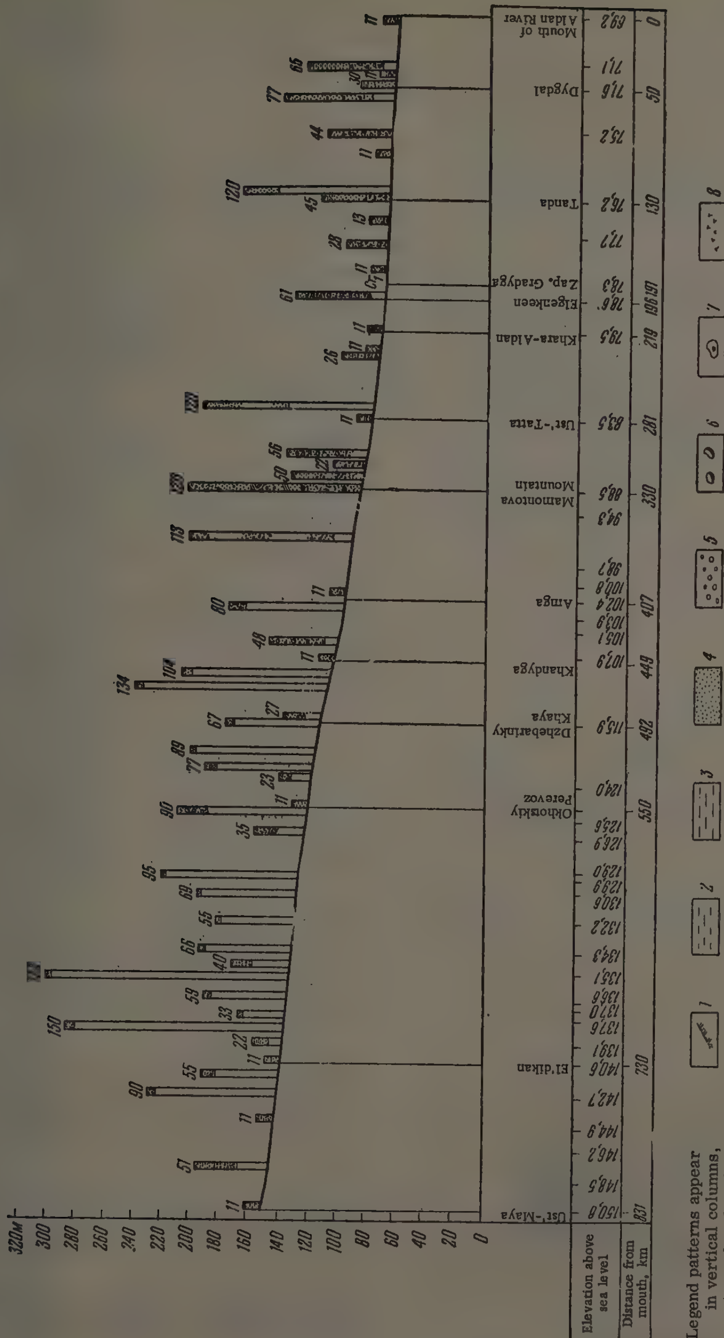
[2] The author uses the Quaternary classification proposed by V.I. Gromov, in 1957, at the All-Union Interdepartmental Conference on the Quaternary [5].




[Legend patterns appear in vertical columns, at a reduced scale.]

FIGURE 3. Cross-section along the Aldan (from its mouth to settlement Ust'-Maya).

1 -- soils; 2 -- loam; 3 -- sandy loam; 4 -- sand; 5 -- gravel beds; 6 -- boulders; 7 -- concretions; 8 -- plant remains.

species), Sambucus sp., Nepeta sp., Larix dahurica, L. sp.; Pinus sp.

This terrace is traceable down the Aldan (see cross-section, Fig. 1) where it contains the same fauna and flora. In addition, a tooth has been found in these deposits, in the lower course of the Aldan; according to E.A. Vangengeym, it belongs to Elephas primigenius (early type), which fairly well dates these deposits as belonging to the second half of the middle or the beginning of the upper Pleistocene.

Developed everywhere along the middle and lower Aldan course is a terrace 11 to 15 meters high (Fig. 1). It is made up of loam, sandy loam, sand, and gravel, whose upper Pleistocene age has been established from numerous findings of an upper paleolithic fauna (Elephas primigenius, late type; Rangifer tarandus, etc.).

Deposits of the high and low flood plains, as well as of the islands, bars, and channel, are Holocene. The high flood plain deposits are 5 to 6 meters thick; the low, 2 to 3 meters; both are made up of loam, sandy loam, sand, and gravel.

We shall now turn to the occurrence and nature of Cenozoic deposits in the lower course of the Aldan.

Tertiary deposits associated with the 100 to 120 meter terrace are represented here more fully. They are exposed in Mamontova Mountain, on the left bank, 325 kilometers above the mouth of the Aldan River. Resting at the base of the southeastern and higher part of the exposure, there are kaolinite sands, locally cemented by iron oxide. The sands carry lenses of clay and occasional pebbles. Many plant remains (fruit of Juglans cinera, coniferous cones) and concretions have been collected here. As determined by N.P. Chervinskiy, the latter are made of siderite and goethite-hydrogoethite. According to him, they were formed in stagnant water in a temperate, humid climate. This unit is up to 30 meters thick.

The following stable minerals were determined in thin sections[3] (in %): Magnetite, 0.4; ilmenite, 45.3; pink garnet, 52.0; sphene, 0.2; rutile, 0.4; and zircon, 1.7. Tertiary deposits in the Lena valley have about the same mineral composition.

Concretions carry plant remains among which A.N. Krishtofovich and A.F. Yefimova have identified the following: Magnolia sp., Juglans cinera, Corylus, Acer, Salix, Betula, Alnus, Equisetum, etc. From the same sands, A.P. Vas'kovskiy has determined Pinus monticola Douge and P. Radiata Douge [3].

According to data from spore pollen analysis,[4] the vegetation was fairly diversified at the time of formation of the above-described sandy unit. Among gymnosperms, it included Picea cek. Omorica; Picea cek. Cembra; Abies; Tsuga, etc. Angiosperms were represented by divers species: Alnus, Betula sp., Ulmus, Quercus, Ilex, and Juglandaceae.

Considering the lithologic features of these deposits, the data of mineral and spore pollen analysis, and the numerous macrofloral findings, the age of this sandy unit undoubtedly is Tertiary [7].

Higher in the section, there is a ferruginous gravel unit, a few centimeters thick. Still higher up, there are sands, light gray to yellow, mixed-grained, cross-bedded, kaolinite, with pebbles; they are 40 to 45 meters thick and also carry plant remains, although in smaller amount.

Analysis of thin sections from these sands gives the following composition, in %: Magnetite, 0.4; ilmenite, 28.3; pink garnet, 68.0; epidote, 0.2; rutile, 1.3; sphene, 0.1; zircon, 1.7. These results point to a similarity of the upper unit with the lower ones. These sands appear to have been deposited shortly after the lower sequence and are very close to it in age, both being Tertiary. A more precise dating of these sands is difficult. Still, it should be noted that, the Mamontova Mountain deposits are older than those from the lower course of the Lena (Saardakh Island), being probably Miocene or Pliocene.

Capping this section are upper Pleistocene eluvial and diluvial deposits, only 0.5 to 2.5 meters thick. They have yielded mammalian bones belonging to Elephas primigenius, Bangifer tarandus, Rhinoceros antiquitatis, Equus caballus, and Bos sp.[5]

Along the lower Aldan, Tertiary deposits are exposed at the base of many terraces. The highest such basal unit, 10 to 12 meters thick, has been observed at the Chuysk

[3] Analyses of the heavy fraction in thin sections were performed by Yu.V. Bulavaya.

[4] All spore pollen analyses were made in the laboratory of the Geological Institute of the Academy of Sciences, U.S.S.R., by R.Ye. Giterman and G.M. Bratseva.

[5] All identification of mammalian bone remains were done by E.A. Vangengeym, a collaboratrix in the Geological Institute of the Academy of Sciences, U.S.S.R.

exposure, on the right bank, 30 kilometers above the mouth. Occurring at the base of the section, here, are gray sands, locally ferruginous, kaolinite, cross-bedded, with pebbles and plant remains. Well rounded cones and fruit of Juglans cinera were collected there.

Predominant in thin sections is ilmenite, with a small amount of magnetite and a considerable amount of pink garnet present along with some hornblende, epidote, sphene, rutile, zircon, and kyanite.

Pollen of Pinus, Picea, Betula, Abies, Alnus, Tsuga, Pterocarya, Quercus, Ulmus, and Juglans were identified by R.Ye. Giterman, from two samples of these sands.

Tertiary deposits occur in the valleys of both the right and left tributaries of the Aldan (Tanda, Tatta, Tumara, Zapadaya Gradyga, Vostochnaya Gradyga Rivers); consequently, they are well developed. In addition, as determined by drilling, they reach up to 500 meters on the left bank, and 700 meters on the right; however, they thin considerably, to the east. While their visible thickness in Mamontova Mountain is 80 meters, where they dip under the Aldan water edge, they never reach the surface 120 kilometers upstream (to the east). A borehole at Khandyga village penetrated about 60 meters of similar deposits resting on Cretaceous sand and poorly cemented sandstone.

Resting locally on the eroded surface of Tertiary sediments is thin gravel cemented by iron oxide. Bones appear to have been found in this ground, including Elephas cf. namadiscus, Equus cf. sanmeniensis, Alces latifrons, Trogontherium cf. cuvieri, which, according to E.A. Vangengeym, are typical of the Yakutian Eo-Pleistocene.

In the Chuysk exposure, Tertiary sands are overlain by a thin pebble bed (several centimeters thick) with strongly decomposed pebbles of volcanic rocks. This pebble bed, probably Eo-Pleistocene, becomes several meters thick, in the Tumara basin.

Thus, the Eo-Pleistocene pebble beds along the lower Aldan rest in erosional remnants at the base of younger Quaternary terraces. In the middle Aldan valley, they evidently make up the alluvium of the 80 to 90 meter terrace.

Best developed here are the 25 to 35 meter terrace deposits. The height of this terrace varies considerably locally. For example, its maximum is 65 meters in the so-called Chuysk exposure, on the right bank of the lower Aldan, 30 kilometers about the mouth. This is connected with the overlying glacial deposits, widely developed on the right bank.

Exposed in a terrace cliff is the following section:

$Q_3^{ped}$ 1. Soil, 0.4 to 0.5 meter thick;

$Q_3^{e-d}$ 2. Gray, porous loam, 1 to 1.5 meter thick;

$Q_2^{2-3fgl,\ d-slf}$ 3. Gray sandy loam, locally ferruginous, with shells. Occasional lenses of sand with pebbles and plant remains (numerous Larix dahurica cones); 12 meters;

$Q_2^{2-3fgl}$ 4. Boulder bed of assorted pebbles and boulders, with predominant gray sandstone (Verkhoyansk material) carrying lenses of dark gray fine-grained sand with plant remains, 6 to 7 meters;

$Q_1^{2al}$ 5. Bed of pebbles, ferruginous, weathered, consisting of extrusive rocks; this composition is not typical of the overlying boulder bed, and the material is not Verkhoyansk but rather alluvium from an older, deeply eroded terrace; this bed is only several tens of centimeters thick.

$N^{al}$ 6. Sand, 10 to 12 meters thick.

A Rhinoceros jawbone was found in loam of unit 2, which suggests an upper Pleistocene age for these deposits.

A.I. Moskvitin identified shells of Valvata pulchella, Sussinea oblonga, etc. from sandy loam of unit 3. Sand lenses yielded numerous fragments of rodents, Lemmus obensis, Lepus timidus, Dicrostonys torquatus, Ochotona hyperborea, Microtus sp., etc. A tooth fragment of Elephas primigenius (early type) also was found here.

The mineralogic composition of the heavy fraction in sandy loam is as follows (in %): Magnetite, 38; ilmenite, 27.7; pink garnet, 18.8; pyroxene, 13; zircon, 5.6; rutile, 1.9. Of interest is the considerable amount of pyroxene and magnetite.

The spore-pollen analysis data (Fig. 2) show that the period of deposition of sandy loam was marked by grassy vegetation. Present among woody plants were birch (including Betula nana), pine, and larch; the pollen assemblage is diversified. Most likely, large areas were taken over by the forest and tundra. This is not contradicted by the findings of seeds. Yu.M. Trofimov identified the following plant seeds: Nymphea candida Presb., Hippuris vulgaris L., Menyanthes trifoliata L., Sambucus sp., Carex rostrata Stok., etc. These data fit well into the faunal findings, both suggesting a rather rigorous climate. The finding of Elephas primogenius (early type) suggests the second half of the Middle to the beginning of the late Pleistocene.

The sandy loam and the underlying boulder bed are connected spatially with morainal deposits of the Aldan right bank area. From the position of these deposits and from paleontologic data for the Tumara valley [8], they, too, should be assigned to the close of the middle or the beginning of the late Pleistocene. On the right bank, this terrace has the same structure all along the lower course.

$Q_3^{e-d}$ 2. Loam, brown, dense, porous (loess-like); 1 meter thick;

$Q_2^{2-3al}$ 3. Loam, dark gray, bedded, with plant remains and occasional fossil ice; 9 meters thick;

$Q_2^{2-3al}$ 4. Gray sand, fine-grained, cross-bedded, with lenses of coarse sand and pebbles; 10 to 12 meters thick, with talus below.

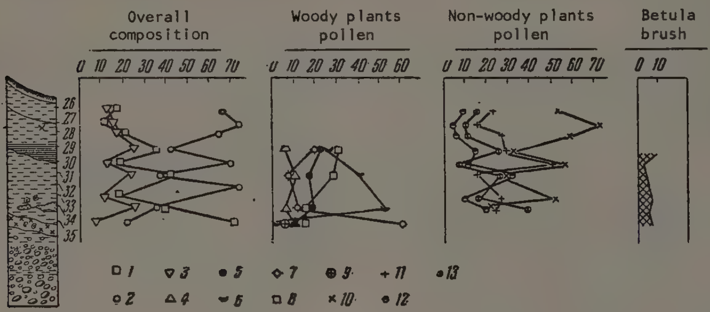



FIGURE 2. Pollen diagram of loam from the Chuysk exposure.

1 -- pollen of woody plants; 2 -- pollen of grasses; 3 -- spores; 4 -- Picea; 5 -- Pinus; 6 -- Larix; 7 -- Betula; 8 -- Alnus; 9 -- Salix; 10 -- Chenopodiaceae; 11 -- Altemisia; 12 -- Gramineae; 13 -- mixed grasses.

The following section is exposed in a 28 meter cliff, 22 kilometers below the mouth of Zapadnaya Gradyga (right tributary of the Aldan):

$Q_3^{ped}$ 1. Soil, 0.5 meter thick;

$Q_2^{2-3fgl,\ d-slf}$ 2. Dark gray, dense loam, with isolated boulders, changing downward to dark gray fine-grained sand; 1 to 1.5 meter;

$Q_2^{2-3\ fgl}$ 3. Boulder bed, fairly well cemented by sandy clay, with numerous pebbles; both boulders and pebbles vary in size and degree of rounding. Petrographically, the sandstone is very monotonous (exclusively Verkhoyansk material). Thickness, 5 to 6 meters, with talus below.

Mollusk shells and rodent bones, similar to those from the Chuysk exposure, were found in loam of unit 2.

On the left bank of the Aldan, this terrace is somewhat different. The following section is exposed in a cliff, 21 kilometers below the mouth of Tatta (left tributary of the Aldan):

$Q_3^{ped}$ 1. Soil, 0.5 meter;

A strongly ferruginous sand with plant remains is exposed along the edge of the stream (Tertiary basement). Mollusk shells (Succinea oblonga, Valvata pulchella, etc.) were found in the loam of unit 3. On the slope and at the base of the exposure, bone fragments of Rhinoceros sp., Equus caballus, and Cervus elaphus were collected. They all are representatives of the upper Paleolithic faunal complex, characterizing most likely the loam directly under the soil. The spore-pollen analysis data (Fig. 3) show that grassy vegetation prevailed during the formation of the loam unit.

Thus direct relationship is demonstrated for the lower Aldan, between glacial deposits and a typically alluvial sedimentation. Such relationship affords a determination of the position of glacial deposits in the stratigraphic column compiled chiefly from non-glacial data.

Developed in both the lower and middle courses of the Aldan are loam, sandy loam, sand, and gravel, related to the 11 to 15 meter terrace. A section of these deposits has been observed on the right bank, at

Krest-Khal'dzhay village, where the following section is exposed in a 15 meter cliff:

$Q_3^{ped}$ 1. Soil, 0.25 to 0.3 meter;

$Q_2^{3al}$ 2. Dark gray loam, locally stratified, with plant remains and fossil ice, 3 to 4 meters thick;

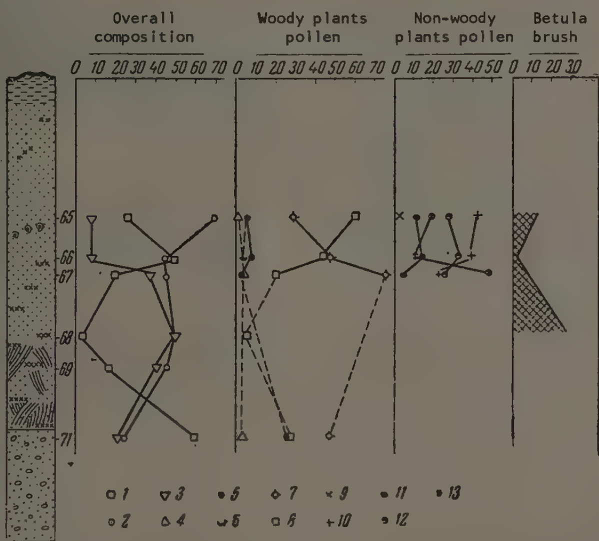



FIGURE 3. Pollen diagram of sandy deposits in a terrace on the left bank of Aldan, 21 kilometers below the mouth of Tatta River.

1 -- pollen of woody plants; 2 -- pollen of grasses; 3 -- spores; 4 -- Picea; 5 -- Pinus; 6 -- Larix; 7 -- Betula; 8 -- Alnus; 9 -- Salix; 10 -- Chenopodiaceae; 11 -- Altemisia; 12 -- Gramineae; 13 -- mixed grasses.

$Q_2^{3al}$ 3. Gray sand, fine-grained (oozy), locally ferruginous; 1 to 1.5 meters;

$Q_2^{3al}$ 4. Loose gravel; visible thickness, 1.5 to 2 meters, with talus below.

Loam from unit 2 yielded bone fragments of Equus caballus, Rhinoceros antiquitatis, Bos sp., Cervus sp. (Alces), Rangifer tarandus, Cervus elaphus.

On the basis of numerous faunal findings in situ, and because of the relationship with alluvium from higher terraces and the flood plain, these deposits are definitely late Pleistocene. This is not contradicted by the spore-pollen analysis data.

Late Pleistocene loams overlie all of the Aldan terraces. As a rule, they carry an upper Paleolithic fauna. They are rather thin, up to 2 meters thick. Such deposits are developed not only in the Aldan valley but also on the Lena-Aldan watershed where they also are fossiliferous. This is the reason for assuming that they are contemporaneous, despite their difference in elevation. Loams are also widely developed in the Vilyuy valley and on the Lena-Vilyuy watershed where they were identified by the findings of an upper Pleistocene fauna [6].

Holocene deposits are much more widely distributed in the lower Aldan course than in the middle. Their composition depends on the whole on that of the eroded rocks. Where coarse clastic material from the Aldan shield predominates, on the whole, in the middle course, the Holocene of the lower course is represented mostly by sand and thin loam. It should be noted, however, that the section

on the right bank of the Aldan is made up of boulder-gravel deposits with Verkhoyansk material predominating.

## CONCLUSION

1. The middle course of the Aldan is marked by thin Tertiary deposits and by their relationship with high terraces. The deposits are thicker in the lower course and their mode of occurrence changes. This suggests intensive Tertiary subsidence along the lower Aldan course and an uplift and incision in the middle course.

Numerous findings of plant macro-remains together with the spore-pollen analysis data suggest a prevalence of pine to broadleaf forests. The climate was warm and relatively humid. A further differentiation of Tertiary sequences runs into considerable difficulties at the present time; therefore the age of the Mamontova Mountain deposits can be designated approximately as Miocene or Pliocene.

2. Where intensive Tertiary subsidence took place along the lower Aldan course, the tectonic situation was different in the Quaternary. Cessation of the subsidence is suggested by the lack of thick Quaternary deposits. Gravel beds, overlying Tertiary sand, have an aspect different from younger deposits. The findings of the Eo-Pleistocene fauna apparently were from the latter.

3. Widely developed in this stretch of the Aldan valley are deposits belonging to the second half of the middle Pleistocene; they have been brought about by intensive aggradation by the river. These deposits are adequately identified by the faunal findings which not only established their age but help in reconstructing the paleogeographic environment during their deposition. All these findings suggest a rigorous climate. The presence of such rodents as Lemmus obensis, Dicrostonyx torquatus, etc., suggests conditions close to those of the tundra. The findings of marco-flora (numerous Larix dahurica cones), together with the spore-pollen analysis data, not only confirm this assumption but refine it, too. The presence of grassy vegetation with an addition of such woody plants as Betula nana and Laryx dahurica definitely suggests forest-tundra conditions.

All of these data go a long way in revealing the events taking place in the mountains affected by glaciation.

The upper Pleistocene witnessed the formation of the 11 to 15 meter terrace which is widely developed in the middle and lower Aldan course. The climate was fairly rigorous, which is confirmed by numerous faunal findings and by the spore-pollen analysis data.

The data collected made possible a general outline of the stratigraphic column subject to supplement and correction.

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Received October 27, 1958

## THE AGE OF TEKTITES[1]

by

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The nature of tektites has not yet been determined. There are many theories which assume either their terrestrial or cosmic origin. In chemical composition, tektites are closer to sedimentary rocks than to obsidian, despite an external resemblance to the latter. Absolute age determinations are of great interest in the problem of the origin of tektites.

Working with the K-Ar method, E.K. Gerling and M.L. Yashchenko [1], also H.E. Suess, R.J. Hayden, and M.G. Inghram [2] have determined that the age of various tektites falls in the range $1.7 \times 10^7$ to $7.3 \times 10^6$ years; this is considerably less than the age of stony meteorites. It should be noted that the argon content was very low in all specimens. However, this low argon content and the correspondingly young age of tektites under study may have been brought about by the remelting of the original material.

Age determination by the lead method is of considerable interest because it gives a first approximation for the age of meteoritic material. As far as we know, no results of such determinations have been published.

The Committee on Meteorites kindly put at out disposal a tektonite specimen, Indochinite, which we have analysed.

The isolation of lead was done by the pyrochemical method, with a radioactive tracer and with subsequent colorimetric determination. Uranium was determined by the luminescent method after having been isolated by an ehter extract; the isotope composition of lead was determined mass-spectrometrically.

[1] K voprosu o vozraste tektitov.

The results were as follows: 1) the uranium content was $1.7 \times 10^{-6}$ gram/gram; 2) the lead content, $7.6 \times 10^{-6}$ gram/gram; 3) the isotope composition of the tektite lead was $Pb^{204} = 1$; $Pb^{206} = 28.91$; $Pb^{207} = 17.53$ and $Pb^{208} = 41.87$.

Assuming that tektites are cosmic bodies, and introducing the Patterson correction for primordial lead from its isotope composition in iron meteorite, we arrive at the following figures for the absolute age: $Pb^{206}/U^{238} = 4.7 \times 10^9$ years; $Pb^{207}/U^{235} = 4.2 \times 10^9$ years and $Pb^{207}/Pb^{206} = 3.7 \times 10^9$ years.

However, it may be supposed that tektites originated as a result of remelting of terrestrial sedimentary rocks in the course of some thermal processes. In that event, by introducing a correction for the isotope composition of Tertiary or Quaternary lead (i.e., for the time of their remelting), we obtain, from all three ratios, an age of about three billion years, instead of the anticipated several million. Consequently, the correction for Tertiary lead is meaningless, with the Indochinite specimen, and it appears that the material of this tektite cannot be of a terrestrial origin. Indeed, if this tektite had resulted from remelting of individual specimens of sedimentary rocks, its formation out of rocks with such an anomalous lead isotope composition is improbable because of their scarcity.

Anàlysis of an isolated tektite specimen is not enough for a final judgment; however, the result so obtained is additional evidence for a cosmic origin of tektites.

The work on the absolute age determination of tektites is being continued.

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Received September 9, 1958

## XENOLITHS IN DIORITE PORPHYRY DIKES OF THE EASTERN UPPER YANA REGION[2]

by

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In 1954, diorite porphyry dikes were discovered in the (south) Yuzhno-Verkhoyansk synclinorium, in the Dyby polymetal area (Prokhladnyy Creek and Menkech River, a tributary of the Dyba); in places, these dikes carry xenoliths of extrusive and metamorphic rocks, most of them not observed in that vicinity, as yet. A petrographic study of these xenoliths was made by Ye.N. Rodnova, S.V. Domokhotov, and the author.

The dikes cut and alter a body of alternating sandstone, shale, and sandy shale of the Upper Permian Menkech formation, in the meridionally trending Dybin brachyanticlinal fold. The beds dip at 18° to 30°.

In the Prokhladnyy Creek area, diorite porphyry cuts a thick (18 to 20 meters) transverse (105° to 110°) granite porphyry dike. As a result of contact metamorphism, aplitic and microgranite structures were formed in the dike groundmass, while dark minerals of the inclusions were chloritized and muscovitized

Diorite porphyries are massive, dense, greenish gray rocks; their texture is determined by the presence of inclusions of plagioclase and complex pseudomorphs after dark porphyry components. The inclusions range in size from 1.5 to 3.5 millimeters.

The groundmass is prismatic-granular, with elongated prismatic crystals of plagioclase and dark minerals, 0.2 to 1.0 millimeter long.

Diorite porphyry consists of strongly altered plagioclase (50 to 55%), chlorite (25% to 30%), carbonates (about 5%), quartz (5%), leucoxene (1 to 2%), and apatite.

A typical feature of diorite porphyry dikes is the presence of xenoliths of acid, basic, and hybrid extrusives. Present among the acid xenoliths are:

1. Coarsely crystalline biotite granite consisting of crystals of gray quartz (25%), white feldspar, and biotite (8 to 10%).

2. Granite porphyry changing to granodiorite porphyry with a porphyritic texture.

The groundmass which cements the inclusions is hypidiomorphic granular. Arranged in decreasing degree of their idiomorphism, the minerals make up the following series: biotite, plagioclase, K-Na-feldspar, and quartz. Locally, the groundmass is micropegmatitic.

The mineral inclusions are represented by plagioclase (50 to 70%), K-Na-feldspar (10% to 15%), biotite and its pseudomorphs (7% to 10%), and quartz (10 to 25%).

Predominant in the groundmass is K-Na-feldspar (45 to 65%), with some quartz (10% to 25%), plagioclase (0 to 5%), ore minerals (magnetite or ilmenite?, 4 to 5%), apatite (about 1%), and zircon (less than 1.0%); secondary minerals, chlorite and carbonates, are developed on biotite and to a smaller extent on feldspars.

3. Quartz-hornblende diorite, prismatically crystalline. Plagioclase and colored minerals are developed in idiomorphic elongated prismatic crystals, with the interstices filled with xenomorphic quartz grains.

This rock consists of plagioclase (55% to 60%), brown hornblende (about 15%), biotite (approximately 5%), K-Na-feldspar (5%), quartz (about 10%), magnetite (3 to 4%), and apatite (1.0%). The following secondary minerals are present: sericite, carbonates, and pelitic particles developed on plagioclase; chlorite, which locally fills the interstices in association with carbonates and quartz, developed on hornblende.

4. A hornblende intrusive rock whose porphyritic structure is due to the presence of coarse (up to 2.0 centimeters) inclusions of green to brown hornblende in a dark-gray, not fully crystalline groundmass.

5. Black micaceous metashale.

6. Micaceous quartzite.

7. Andalusite-cordierite hornfels.

Xenoliths of basic intrusives are from

[2]Ksenolity v daykakh dioritovykh porfiritov vostochnogo Verkhoyan'ya.

0.04 meter to 0.30 meter, with sinuous and fused outlines. They often occur in accumulations within the dike.

The following varieties occur in this group of xenoliths:

1. Chloritic hornblende gabbro dissected by fine (1.0 to 1.5 millimeter) veinlets of milky white quartz.

2. Chloritic hornblende porphyry with pyrite incrustations.

3. Quartz gabbro-diorite, hypidiomorphic, marked by the difference in the degree of idiomorphism in its component minerals. Among the latter is an amphibole, more idiomorphic than plagioclase; and apatite in idiomorphic inclusions in the amphibole.

This rock consists of brown hornblende (40%), monoclinic pyroxene (5%), plagioclase (50 to 55%), apatite (less than 1.0%), ilmenite (2 to 3%, and clinozoisite developed in some of the interstices.

Secondary minerals are represented by chlorite usually developed on No. 31 pyroxene, less commonly on amphibole.

Such are, briefly, the xenoliths observed in diorite porphyry dikes; they are of importance as indirect evidence of the nature of the ancient basement in the (south) Yuzhno-Verkhoyansk synclinorium.

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Received July 12, 1958

## THE HEAVY FRACTION MINERALS FROM THE ALDAN-OLEKMA WATERSHED[3]

by

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The Aldan-Olekma watershed is a western continuation of the South Yakutiya coal measures. The latter are divided into the eastern, central, and western regions.

Coal measures of the eastern regions were studied by Yu.K. Dzevanovskiy [1, 2]. The Central region was studied in 1952 and 1953 by V.V. Mokrinskiy, I.I. Sharudo, and by T.A. Ishina. A group from the South Yakutsk Geological Exploration Expedition, the Chita Geological Administration, also studied this area [4]. V.G. Ditmar (1948) briefly described the western region coal measures.

The first lithologic study of the coal-bearing rocks was done by this author. The coal-bearing sequence consists of alternating well-cemented sandstone, siltstone, and shale, with intercalations and lenses of gravel and conglomerate, and with coal beds. The determination of primary lithogenic features of these rocks and careful analysis made it possible to identify among them lacustrine, flood plain, marsh, and river or channel facies, as well as alluvial fan facies.

A rhythmic alternation is present in the coal-bearing section, with well defined major and minor sedimentary rhythms. This regular alternation of sediments in the section allowed its differentiation into four macrorhythms and the corresponding four coal-bearing formations: the Yukhtinsk, Chul'man, Duraysk, and Gongrinsk. The formation names are those designated for the central region. The total thickness of the coal measures is estimated at 750 to 800 meters.

The lithologic varieties of rocks were studied in thin section, with a simultaneous determination of the heavy fraction minerals. Used in differentiation in a heavy fluid was the 0.1 to 0.01 millimeter fraction as the richest in heavy minerals [4]. Among heavy minerals present in the coal-bearing rocks are iron hydroxides, pyrite, siderite, carbonates, zircon, apatite, garnet, rutile, octahedrite, sphene, leucoxene, undifferentiated titanium rock fragments, tremolite, the epidote-zoisite group minerals, tourmaline, cassiterite, orthite, biotite, muscovite, and chlorite. There are isolated grains of hornblende and pyroxene, and some specimens carry a large amount of ore minerals.

The qualitative ratio of heavy minerals, both vertically and laterally, is inconsistent, with the content of individual minerals varying ten and more times. The most common heavy minerals are iron hydroxides, pyrite, zircon, apatite, garnet, rutile, octahedrite, sphene, leucoxene, the epidote-zoisite group, and biotite. Given below is a brief morphologic description of the most representative minerals

Iron hydroxides occur as crust-like to spherical bodies or irregular, reddish to drab brown fragments. Fine grains or aggregates of pyrite commonly occur in a close association with iron oxides. In the Chul'man and Duraysk formations, iron hydroxides form a typical ferruginous dappling.

[3] Mineraly tyazheloy fraktsii uglenosnykh otlozheniy Aldano-Olekminskogo mezhdurech'ya.

Pyrite occurs in fine isolated grains or in aggregates; the coarser grains have well-defined cubic faces. Pyrite grains are commonly covered by an iron hydroxide crust.

Zircon is present in prismatic, rounded, and fragmental colorless to pale pink grains. Individual beds carry thin prismatic varieties of colorless zircon. The fragmental varieties are colorless to pale pink. The thick prismatic and rounded varieties of zircon are mostly pink. Observed in sandstone and siltstone of the middle part of the Chul'man formation were thin, short prismatic grains and fragments of deep pink to brown zircon.

Apatite occurs in prismatic grains, gray on a fresh break and brownish in semi-decomposed varieties. Grains and fragments of fresh apatite predominate. Present along with the prismatic grains in some Chul'man sandstone layers are coarse tabular grains of fresh apatite and rounded fragments of semi-decomposed varieties.

Garnet has been observed in isometric, slightly rounded to irregular grains and fragments, usually yellowish to brownish. A certain gradation in the garnet fragments coloring has been observed on the Olekma slope. A colorless garnet is present in the Yukhtinsk formation rocks; garnet in the overlying Chul'man sandstone is also colorless but has a tile-like structure. Pink and blue garnet appear along with the colorless in the overlying formations. No inclusions, especially of the cement-free varieties, have been observed in garnet.

Rutile occurs in several varieties. Its prismatic grains are drab brown; fragmental grains are brown, and tabular grains are dark brown. Some sandstone carries occasional thin prismatic drab yellow rutile grains with elongated and sharpened ends and straight edges. Less common is rutile in heart-shaped twin growths of short prismatic grains.

Octahedrite (anatase) occurs in irregular fragments and grains, tabular to bipyramidal, without any special changes throughout the section.

Sphene has been observed in aggregates and in isolated fine colorless to golden brown grains.

Epidote-zoisite group is represented by fragments and grains, prismatic, rounded to irregular. The distribution and the manner of occurrence of minerals from this group, throughout the section, is of importance. In the Yukhtinsk formation, they are almost colorless or tinted in yellow hues, with epidote predominant. Higher in the section, the minerals of this group range from yellowish green to green to vivid green. The association of epidote with chlorite is typical of the Duraysk formation.

Biotite occurs in plates and in fine irregular scales and shreds, in rocks of the lower part of the section; it is reddish brown to brown in the Chul'man formation and chiefly dark brown in the upper formations. Biotite from the Duraysk formation is marked by numerous inclusions of rutile.

A study of typomorphic features of heavy minerals from the coal measures of western South Yakutiya has led to the identification of several assemblages of stable minerals [5] and to some preliminary conclusions.

1. The following assemblages have been identified: 1) zircon-apatite with a considerable amount of authigenic epidote and siderite; 2) zircon-garnet with apatite and titanium minerals of the epidote-zoisite group; 3) apatite-zircon with a considerable amount of epidote-zoisite and chlorite; 4) garnet-apatite-zircon with a higher content of biotite and chlorite.

The zircon-apatite assemblage is represented by the Yukhtinsk formation. The overlying Chul'man rocks are marked by the zircon-garnet association. The Duraysk formation carries the apatite zircon assemblage; finally, the garnet-apatite-zircon assemblage occurs in the Gongrinsk formation.

2. It has been determined that arkosic sandstones are richer in zircon and garnet, while polymictic sandstones have a higher content of apatite, chlorite, titanium minerals, leucoxene, and epidote-zoisites.

3. Several features are suggested in the distribution of heavy minerals in sediments of various facies types: a) coarse-clastic deposits of alluvial fan facies are richer in zircon and ore minerals; b) lacustrine-flood plain facies are marked by a comparatively high content of pyrite, carbonates, iron hydroxides, and siderite in some horizons; c) the marsh facies contain mostly pyrite, small fragments of apatite and zircon, and a higher amount of sphene, garnet, and much biotite — especially in the upper part of the section.

4. These heavy minerals and their typomorphic features suggest the source of clastic material was in the adjacent Stanovoy uplift, as a result of erosion of ancient acid crystalline rocks.

A study of heavy minerals from the coal measures and the determination of their definite associations confirm our earlier classification of these sediments into formations;

furthermore, it has been demonstrated that heavy minerals, if studied in sufficient detail, can be used in correlating major intervals in coal-bearing sections of the South Yakutian and adjacent Mesozoic troughs.

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Received March 6, 1958

# VIKTOR ALEKSANDROVICH PRIKLONSKIY (MEMORIAL)[1]

This year, Soviet science suffered a heavy loss. Professor V.A. Priklonskiy, an outstanding and talented scientist in the field of hydrogeology and engineering geology and a Corresponding Member of the Academy of Sciences, U.S.S.R., suddenly passed away, on 13 February 1959, in the full bloom of his creative activity. For almost 35 years he worked for the cause of science and he acquired wide recognition in various fields of geology: hydrogeology, hydrogeochemistry, engineering geology, pedology, and lithology.

V. A. Priklonskiy was born February 8, 1899. In 1920 he graduated from the ethnologic-linguistic division of the social sciences department, Moscow State University, and in 1928 from the geologic exploration department, Moscow Mining Academy. He began his scientific career in 1925 when he participated, together with F.P. Savarenskiy, in extensive geologic and hydrogeologic study of the Eastern Trans-Caucasian plain. As a result of many years of study, he published his monographs, _A Hydrogeologic Outline of the Mil'skaya Steppe_ (1930) and _A Hydrogeologic Outline of the Eastern Trans-Caucasian Plain_ (1932).

In these works, V. A. Priklonskiy set forth the general regular patterns in the formation and distribution of various types of groundwater, tying them up with the geologic history and the climatic features of the Eastern Trans-Caucasian depression. These monographs have been widely used in detailed investigations.

In 1930, he joined the S. Ordzhonikidze Geological Exploratory Institute, Moscow, first as an Assistant, then Associate, and finally Professor of Engineering Geology, in which capacity he worked till the end.

[1] Pamyati Viktora Aleksandrovicha Priklongskogo.

At the invitation of Academician A. G. Arkhangel'skiy, Viktor Aleksandrovich worked from 1935 on at the Geological Institute, Academy of Sciences, of the U. S. S. R., while keeping up his teaching at the Institute. In his works of that period, he continued to develop his favorite thesis of regular patterns in the formation of the chemical composition of groundwater in irrigated arid regions and of the relation of groundwater and vegetation.

His general work on the chemistry of groundwater is the well-known compendium, written in collaboration with F. F. Laptev, A Study of Physical Properties and the Chemical Composition of Groundwater, published in 1935, second edition in 1949, and translated into Polish, Hungarian, and Chinese.

From 1939 to 1943, since the creation of the Commission on Hydrogeology and Engineering Geology at the Academy of Sciences, V. A. Priklonskiy was its Academic Secretary; in 1944, when the Laboratory of Hydrogeologic Problems was created at the Academy, he became its Senior Scientist.

Engineering geology was another field in which he was scientifically active. Most of his works were in this field, where he is rightly regarded as one of the founders of ground engineering. Included in his research were problems of general and regional genetic ground science, of regular patterns in the development of physical and geologic and geologic engineering processes and phenomena, and of the methods of geologic engineering study as applied to different types of construction (hydrotechnologic, industrial, municipal, road, etc).

In 1943 his capital work was published, General Ground Engineering, Part I. republished in 1949 and 1955. In 1952 its Part II appeared, dealing with geologic engineering properties of genetic types. The texts of V. A. Priklonskiy have been translated into Romanian, Polish, Chinese, and other languages.

In 1950, V. A. Priklonskiy defended his thesis for the degree of Doctor of Geologic-Mineralogic Sciences: Geologic Principles of Ground Engineering. In the same year, he was awarded the rank of Professor.

He directly participated in the publication of the first major manual on geologic engineering study for municipal construction (1950) and of a manual for such studies in hydroelectric construction.

He worked out a system of indexes describing the physical and mechanical properties of rocks. Particularly important is his "compactness index" and the 1949 "plasticity index," both gaining wide recognition in the evaluation of clay ground.

In 1953, A. Scampton proposed a colloidal activity index, under another name but duplicating the Priklonskiy "plasticity index."

V. A. Priklonskiy was the author of many geologic engineering rock classifications for the U. S. S. R.; a scheme of consecutive formation of geologic engineering properties of sedimentary rocks, in the course of their diagenesis, epigenesis, and early metamorphism; and a classification of geologic engieering processes by construction types.

On his initiative, the Laboratory of Hydrogeologic Problems organized in 1950 an engineering geology laboratory for the study of physical, mechanical, chemical, and chemical colloidal properties of rocks. Successfully worked out under his direction was one of the basic problems in engineering geology - that of the development of geologic engineering properties in main types of argillaceous rocks of the U. S. S. R., i. e., the nature of their strength. In working out this problem, V. A. Priklonskiy applied a comprehensive genetic and geologic analysis of the phenomena and processes under study.

His main attention was directed to the study of the origin and nature of properties and to a detailed and comprehensive geologic engineering description of some of the most common regional types of clay in the U. S. S. R. (Khvalynsk clays of the Trans-Volga; Jurassic clays of the Kursk Magnetic Anomaly; Cretaceous clays of the Volga region; the spondylium clays of Kiev; the Recent, Old Chernomorsk, and Neo-Euxinian oozes of the Black Sea; Recent, Jurassic, Aptian, and other quicksands of Salekhard, Moscow, and the Kursk Magnetic Anomaly, etc.); also to the determination of the nature of their strength on the basis of new concepts in colloid chemistry. This research dealt with the problems of compression and osmotic swelling of clay rocks and with processes of salt (diffusion in them, which is of great interest in theoretical and practical aspects of engineering geology as well as hydrogeology, hydrochemistry, and lithology. The results of this study either have published or are being published in topical collections of the Proceedings of the Laboratory of Hydrogeologic Problems, Academy of Sciences of the U. S. S. R., also in individual papers, reports, and monographs.

From 1956 on, V. A. Priklonskiy was Director of this Laboratory, a member of the Bureau of Geologic and Geographic Sciences at the Academy; in 1958, he was elected a Corresponding Member of the Academy.

In the field of hydrogeology and engineering

geology, V. A. Priklonskiy tutored many new specialists and candidates for the Doctor's degree who successfully presented and defended their theses.

He published about a hundred scientific works, many of them of capital significance, which gained for him well-deserved recognition among theoretical and practical students. Many books and scientific papers were published upon his favorable criticism and under his editorship.

For the high quality of his work, V. A. Priklonskiy was commended and rewarded on many occasions by the Ministry of Geology and Mineral Conservation and the Ministry of Higher Education. He was awarded the Academician F. P. Savarenskiy Prize, the Academy of Science Presidium Prize, also the Stalin Prize, and the Order of the Workers' Red Banner and three medals.

V. A. Priklonskiy kept in close contact with the life and efforts of socialist society. For many years he was engaged by the government and departmental organizations as a consultant in our numerous construction projects (hydraulic centers on the Volga, Oka, Kama, Don; the Moscow and the Lenin Canals; the Moscow Leningrad, and Kiev subways).

He was extensively engaged in administrative and organizational work in scientific societies, conferences, etc. He also was active in the social and political field as a member and acting chairman of local and district committees for election to the Supreme Soviets of the U. S. S. R. and R. S. F. S. R.; he actively participated in the social life of the Laboratory end of the Moscow Geological Exploration Institute.

Soviet science and the collaborators and pupils of Viktor Aleksandrovich have lost in him a beloved teacher, an outstanding organizer, and a sympathetic friend.

I. V. Popov, I. M. Gor'kova,
F. V. Kotlov.

# THE PAPER OF I. P. KUSHNAREV AND A. B. KAZHDAN, "ON THE STRATIGRAPHY OF MIDDLE AND UPPER PALEOZOIC EXTRUSIVES IN SOUTHWESTERN SPURS OF NORTH TYAN'-SHAN,'" [1]

by

N. P. Vasil'kovskiy

This paper, published in the Izvestiya, Geol. Series, No. 5, 1958, critically reviews the age classification of upper Paleozoic volcanic formations in southwestern spurs of North Tyan'-Shan', which I worked out in 1947 and refined in the following years [1, 2, 3].

I agree with some of the corrections of I. P. Kushnarev and A. B. Kazhdan. Some of them I did introduce, myself, while I voiced some of the others as a possibility, subject to confirmation. However, I disagree with the most important corrections of these authors.

Mine was the first attempt at a stratigraphic study of upper Paleozoic volcanics in the Chatkal' and Kuramin Ranges, carried out by a continuous search, with errors unavoidable in a new field. My goal was a single historical geologic plan for the entire Chatkal-Kuramin province, essential in compiling its geologic map.

It was hardly to be expected that my classification would stand up, unshakable, as I noted myself in my appeal for corrections. The two authors seem to appreciate my humble effort; the sharpness of their criticism, however, is somewhat strange, inasmuch as they mention only the contradictions in my classification, whose number, so they say, "increases from year to year." The authors, who reworked my maps and those of other geologists, do not seem to be aware of the fact that these maps have been modified once more, and that the latest maps are as different from their maps as the latter are from the preceding ones.

Nevertheless, I am favorably impressed with the essence of these authors' achievements in this major and difficult task, and I regard it with the same respect as the work of my predecessors, even though they, too, made their mistakes and did not compile classifications.

It has been a long time since I was able to do any systematic work in studying the Chatkal Kuramin upper Paleozoic and personally to solve controversial problems and correct errors. And in any event, this is not a task for one man. Working on this problem, besides I. P. Kushnarev, A. B. Kazhdan, and myself, is a group of geologists from the Uzbek Administration, who are remapping the entire region. I am operating now only from their data and from observations which I made during my numerous consulting trips.

Kyzylsuy, Arkutsay, and Karzhansay formations. In my works of 1952 and 1956 [1, 2], I included ten formations in my classification, rather than 11 as the authors state. I did not include the Kyzylsuy formation because of its local distribution and because I was not sure of its independent standing. One cannot agree, however, with A. B. Kazhdan that the Kyzylsuy acid extrusives belong to the Oyasay formation. According to other geologists, they correspond to the Uya or the Minbulak formation. The three other formations, the Arkutsay, Karzhansay, and Sarysiyun, included in my classification in 1952, are of such limited distribution that their exclusion would not affect the classification as a whole, nor the index geologic map. The Karzhansay and Sarysiyun formations, indeed, are not independent [2]; as to the Arkutsay formation, the situation is more complicated.

The Arkutsay intrusive and extrusive porphyrites, closely related to Visean limestones, are distributed over a very limited area, and

[1] Po povodu stat'i I. P. Kushnareva i A. B. Kazhdana "K stratigrafii effuzivnykh svit srednego i verkhnego paleozoya yugo-zapadnykh otrogov severnogo Tyan'-Shanya."

only in Western Karzhan-Tau; I happen to know nearly contemporaneous porphyrites also from the Bol'shoy Chimgan massif and in the southwestern part of the Kuramin Range. The two authors take these porphyrites out of the classification, on the basis of A.B. Kazhdan's observations. He presumably traced the extrusive Arkutsay porphyrites, for 15 kilometers north of Arkutsay River, in the Kyzyl-Bulak valley, where they carry the ever increasing pyroclastic and sedimentary beds represented by tuffaceous sandstones and conglomerates with very rare porphyrite beds. The underlying limestones contain here Spirifer bisulcatus Sow., Choristites ex gr. bisulcatiformis, and upper Visean and lower Namurian goniatites. On this basis, the authors state that the Arkutsay porphyrites belong to the lower Uya formation, conformable on Visean limestones.

I do not share this conviction and I insist that the Arkutsay porphyrites are older than the Uya formation. I state this for the following reasons:

1. Tuffaceous sandstones and conglomerates, noted by A.B. Kazhdan in the Kyzyl-Bulak valley, belong to the upper Uya formation, judging from their position above the beds carrying a Namurian fauna; as such, they cannot correspond to either the Arkutsay porphyrites or a lower part of the Uya formation.

2. The intrusive varieties of Arkutsay porphyrite cut Visean limestones in the Arkutsay area, which defines their lower age limit; pebbles of intrusive and extrusive Arkatsuy porphyrite fill conglomerates at the base of the Uya formation, thereby defining their upper age limit (upper Visean—lower Namurian).

3. The presence of both intrusive and extrusive porphyrites of an age close to the Arkutsay, previously noted in the Bol'shoy Chimgan massif [1], has recently been confirmed by Ye. M. Golovin [4] who recognizes here a "Tournaisian-Visean complex" cut by greenstone porphyrites which he correlates with the Arkutsay.

These data show that Visean limestones locally are closely related to extrusive porphyrites which occur in intercalations or in a rather thin (150 to 200 meters) sequence. Subvolcanic ("intrusive") varieties of porphyrites were formed at the same time.

It must be admitted, however, that these porphyrites are local, subordinated to the Visean limestones, and do not present an independent and consistent body; as such, they should not be considered a distinct formation.

Uya and Minbulak formations. In my numerous reports and talks, as well as in my 1956 paper [2], I voiced my doubts as to the Minbulak Mountain and the Akbulak basin sections belonging to the Minbulak formation. Nevertheless, I give the credit to A.B. Kazhdan rather than to myself [2] for our better understanding the extent and details of the Minbulak formation.

More important is the problem of relation between the Uya and Minbulak formations.

The two authors are quite confident in their uniting these two formations into one. I had the same idea before [2] but I no longer share this opinion. I.P. Kushnarev and A.B. Kazhdan state the following reasons for their assumption: 1) a similarity in the composition of the Minbulak and Uya formations; 2) conformable position of the Uya formation on lower Carboniferous limestones; 3) conformable position, with a slight local unconformity, of the Minbulak formation on lower Carboniferous limestones; 4) a southerly facies change of the Uya sedimentary rocks in the Ugam River basin, with their replacement by the Arkutsay and Minbulak extrusives; 5) correspondence of the Kokserek formation with a Visean-Namurian fauna to the Minbulak and Uya formations.

The first reason is groundless because there is no true similarity between the extrusives of the Minbulak and the Uya formations. In the Karzhan-Tau and the Ugam River basin, to which the Uya formation is confined, it consists only of paleotrachyte and assorted porphyrites, with a total thickness not exceeding 200 or 300 meters. No similar rocks have been found in the Minbulak formation. The Uya formation, on the whole, differs sharply from the essentially extrusive Minbulak formation, by its decidedly predominant sedimentary rocks with a marine fauna. The latter has not been found in the Minbulak formation. I emphasized in my monograph that in the northern Karzhan-Tau sections (along the Dzegirgen and in the upper Ugama) the Uya formation rests conformably upon and transitionally with Visean limestones, while in the southern part of the Karzhan-Tau, this formation, "judging from the appearance of Arkutsaysk porphyrites directly below it, and from the replacement of Visean limestones by sandstone and conglomerate, rests on the Visean with a slight unconformity." I also noted that "this unconformity has not been observed... It is reflected only in conglomerates with pebbles of intrusive rocks."

I have no objections to the A.B. Kadzhan statement that such transitions from lower Carboniferous limestones to the Uya formation are also present in southern Karzhan-Tau, but that is not an observed fact but rather an inference from the assumption that Arkutsay

porphyrites belong to the lower part of the Uya formation. Rejecting my thesis of a local unconformity in the Uya formation soil, these authors do not explain the origin of thick conglomerates in its lower part and of the abundant pebbles of limestone and intrusive rocks in them, which points to deep erosion and consequently to a local hiatus and unconformity. The authors contradict themselves when they recognize a local unconformity at the base of the Minbulak formation. They, themselves, have stated that the two formations are one and the same.

Their third point is not supported by a single fact. To the contrary, the authors themselves speak either of a local unconformity or the position "on a slightly eroded surface of Visean limestones, without an angular unconformity." Nevertheless, the authors derive a conclusion that suits them - that of a merely local unconformity between this formation and the underlying rocks. According to all data known to me, wherever the Minbulak formation is properly identified, it rests on Visean limestones with a clearly defined unconformity.

The fourth point of the authors is to the effect that in the Karzhan-Tau the Uya sediments, gradually disappear to the south, and are replaced by extrusives and pyroclastics, and that unit 5, the uppermost in my composite section for the Uya formation, is overlain by sedimentary volcanic rocks, up to 1,200 meters thick, which I described as the Minbulak formation. According to my data, this formation rests unconformably on the Uya, truncating it; according to A. B. Kazhdan, there is no unconformity and the Uya formation is not truncated but rather thins out. For that reason, the authors conclude that the 1,200 meter sequence cannot be regarded as the independent Minbulak formation but as an upper part of the Uya formation.

As a matter of fact, if there is a southerly replacement of the Uya sediments by volcanics, it is partial rather than complete. Even in the southernmost sections, almost at the emergence of Ugam River from the Karzhan-Tau, and along its left tributary, the Kaygarli, all of the visible part of the formation is formed by thick conglomerates and sandstones with limestone members. As early as 1938, I collected Namurian goniatites from the latter, at the emergence of the Ugam from its Paleozoic gorge.

Thus the disappearance of the entire sedimentary interval represented by the Uya formation, below the Minbulak formation, cannot be explained by its southerly change to extrusive and pyroclastic rocks.

Even according to A. B. Kazhdan's data ([5], pp. 100-101), in the lower Ugam course the Minbulak formation does rest transgressively, directly on Lower Carboniferous limestones, i. e., it cuts off all of the Uya formation, over 1,000 meters thick. To be sure, A. B. Kazhdan makes a reservation that this unconformity is a local one.

Finally, the fifth point is based on a geologic error. The Koksarek formation indeed is a continuation of the Minbulak (I mapped it as the Minbulak) but it rests with an angular unconformity on limestones carrying an Upper Visean fauna; exactly the same faunal assemblage has been observed in a limestone lens at the base of the Koksarek formation itself. This alone is enough to regard this fauna as not in situ [2]. This was confirmed in 1957, by B. V. Poyarkov who determined that the limestone lens is made up of a conglomeratic breccia, with the fauna present in fragments, i. e., redeposited from the underlying Visean limestones.

Thus none of the arguments of I. P. Kushnarev and A. B. Kazhdan proves complete correspondence of the Uya formation to the Minbulak. Nevertheless, I regard this question still moot, because while a contemporaneous age of these two formations has not been proven, neither can it be ruled out. The Uya formation age is determined by the fauna, as falling within a range from upper Visean to and including the Bashkirian stage. The Minbulak formation is barren of fossil fauna (the A. P. Nedzvetskiy report of a fauna in Southern Karamazar was without a confirmation). Its lower age boundary is determined by middle and upper Visean rocks resting with a slight unconformity on limestones; the upper age boundary - by the Minbulak formation being overlain by the Akchinsk, carrying occasional plant remains which suggest, most likely, the Moscovian stage.

It is possible that the entire Minbulak formation is middle Carboniferous, but even then it may correspond to an upper part of the Uya formation. However, even considering the possibility of a contemporaneous age for the two formations, it is still reasonable to regard them as independent - not only because this age relationship has not been proven but also because of their sharp difference in composition and conditions of formation: the Uya formation is essentially sedimentary volcanic, littoral-marine, while the Mingulak formation consists almost wholly of extrusives. Both formations occupy different areas, possibly occurring together only in a small area in Karzhan-Tau. It is there that a solution of the problem of their relationship should be sought.

The Sarysiyun and Nadak formations. New data of the Tashkent geologists have led to the

conclusion that the Sarysiyun formation, where it has been identified by Ye. A. Kochnev in sections in the southwestern part of the Chatkal Range, represents basal beds of the Oyasay formation rather than being independent. This conclusion holds true for the central part of the Kuramin Range, as well (Lashkerek, Pangaz, Rivers etc.). I voiced a similar idea in 1952, and I have not insisted on the independence of the Sarysiyun formation.

As regards the Nadak formation, my correlation of it with the Ravash indeed was wrong. It appears that Z. P. Artemova is correct when she assigns the Nadak conglomerates and sandstones to a new formation, above the Áchkin but below the Oyasay. Both A. P. Nedzvetskiy [3] and myself assumed that this formation was correlative with the Kushaynak formation of southeastern Karamazar. Besides the similarity in their sections and the sequence and composition of volcanics, this correlation was suggested by the presence in them, at numerous localities, of calcareous algae, formerly identified by N. N. Yakovlev as Sycones sponges. Z. P. Artemova, V. N. Tkachev, B. I. Sigalov, and many other Tashkent geologists who did the mapping of the Kuramin Range, have shown that the same formation - which they call the Nadak - is developed very conspicuously in the volcanic section of that range, where it is a marker. This formation is sharply unconformable upon the Akchin and on granitoids overlying it. Its position below the Oyasay formation has nowhere been observed and is only assumed.

On the independence of the Ravash formation. There is no unity of opinion between me and my critics, on this subject, despite the fact that this topic was discussed by I. P. Kushnarev and myself, on our joint trip to the Ravash Mountains where this formation has been identified. Our arguments have been published [1, 2, 5] and there is no need to pause for them here.

I shall only mention the facts confirming the presence of an independent Ravash formation elsewhere. The presence of pebbles of the Kyzylsay and Arashan type granitoids in the Schwagerina zone conglomerates of Kassan Mountain, where these granitoids cut the Oyasay formation, suggests that the Schwagerina zone is younger than the Oyasay. If this is true, the acid extrusives, 1,200 to 1,300 meters thick, conformable on the Schwagerina zone in the vicinity of Ten'ga settlement, should be correlated only with the Shurabsay formation. Here, it is overlain with a sharp unconformity, by a volcanic sequence of the same composition as in the Ravash Mountain, i.e., the Ravash formation. These data, obtained from my observations and from the work of Z. P. Artemova, A. S. Makarova, and other geologists, were once more confirmed by my 1956 observations.

I. L. Turbin has confirmed the presence of a sedimentary volcanic formation in the Kassan basin, where it rests unconformably on the Shurabsay formation and is correlative with the Ravash.

Zh. N. Kuznetsov and V. A. Arapov have confirmed the presence of the Ravash formation in the Kay-Say - Tashkensken - not to the extent I assumed.

These data confirm the independence of the Ravash formation and its wide distribution. This could demolish the most important argument against a pre-Ravash intrusive complex whose extent as yet remains unclear.

Thus the latest variant of an upper Paleozoic volcanic stratigraphic column in southwestern spurs of North Tien-Shan is as follows:

1. Arkutsay porphyrites, developed locally and closely related to the Visean limestone section.

A local unconformity and minor intrusions.

2. Sedimentary volcanic Uya formation, developed only in the Karzhan-Tau; its age -- late Visean to Bashkirian.

3. Minbulak volcanic formation, developed mostly south and southeast of the Karzhan-Tau. It is supposed to be Namurian to lower middle Carboniferous; it is possibly correlative with part or all of the Uya formation.

Unconformity and intrusion.

4. Middle Carboniferous Akchinsk volcanic formation.

Unconformity and intrusion.

5. Kushaynak (Nadak) formation; upper middle to lower upper Carboniferous.

Unconformity and intrusion.

6. Oyasay (and Sarysiyun) extrusive formation, upper Carboniferous.

Unconformity and intrusion.

7. Shurabsay sedimentary volcanic formation.

Unconformity and possible intrusion.

8. Ravash volcanic formation.

Unconformity.

9. Kyzylurak volcanic formation and post-Kyzylnurak intrusion.

This variant includes all main subdivisions of my 1952 classification. The exclusion of the Arkutsay, Kyzylsuy, Sarysiyun, and Karzhansay formations, which designated some extremely poorly developed extrusives, did not detract from the practical value of this classification. It differs from that proposed by A. B. Kazhdan and I. P. Kushnarev in that it recognizes an independent Ravash formation, as well as the independent Uya and Minbulak formations, and includes a new Kushaynak (Nadak) formation.

However, the independence of the latter formation is subject to confirmation. It is not impossible that the Akchin formation is mistaken for it in the Kuramin Range, with the Minbulak formation mistaken for the Akchin.

Should the independence of the Kushaynak (Nadak) formation not be confirmed, that would simplify the classification even more; it will be down to seven principal formations, not counting the Arkutsay porphyrites.

It is clear from the above exposition that much progress has been made in recent years in improving our understanding of volcanics from the southwestern spurs of North Tyan'-Shan'. The well-directed efforts of I. P. Kushnarev and A. B. Kazhdan have been instrumental in these achievements. A further study of the stratigraphy of this province is imperative, chiefly as it pertains to controversial and unsolved problems.

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## E. J. ZELLER'S PAPER, "MISSISSIPPIAN ENDOTHYROID FORAMINIFERA FROM THE CORDILLERAN GEOSYNCLINE"[2,3]

by

N. P. Malakhova

In recent years, American micropaleontologists have applied the results of study of small, chiefly endothyroid foraminifera, in their study of the Paleozoic. Small foraminifera have a wide geographic and a limited vertical distribution, which makes them suitable for stratigraphic differentiation. They are especially important in those areas where Paleozoic macrofauna is either lacking or very scarce. In such instances, small foraminifera can be successfully used in correlating distant sections and in determining their age.

Soviet geologists have long duly appreciated the great value of small foraminifera in geologic and exploration work. As compared with the U. S., and Western European countries, paleontologists of the Soviet Union have achieved great success in the practical use of such foraminifera for stratigraphic purposes.

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[2] O stat'ye Ye. Tsellera "Missisipskiye endotiroidnyye foraminifery iz kordil'yerskoy geosinklinali."

[3] Journal of Paleontology, vol. 31, no. 4, 1957.

pecifically, on the basis of study of small oraminifera from lower Carboniferous deposits corresponding to the Mississippian of the merican stratigraphic scale, detailed stratigraphic differentiations have been accomplished in the Soviet Union. They have found vide application in the geology of the Urals, Donbas, Siberia, and other major provinces. Many monographs have been published, escribing small lower Carboniferous foraminifera from different regions of the Soviet Jnion. The lack of adequate information on oraminiferal assemblages from the Mississippian of the U.S. hampered the correlation f the two lower Carboniferous sections. For hat reason, E. Zeller's paper is of particular interest.

This short, 25-page paper is in two parts. n part one, the author cites general information on the geologic structure of the Cordilleran geosyncline and on the collection of pecimens; he suggests a method of preparing hin sections from specimens taken parallel o the bedding. Much space is given to the escription of stratigraphic sections. Regional tratigraphy of the Cordilleran Mississippian s given and correlated with the Mississippian f the Central States.

The second part contains a systematic escription of new species of foraminifera sed as a basis for zonal subdivision of the ection, along with some companion forms. The paper is accompanied by eight paleontoogic plates with good illustrations.

E. Zeller studied 12 sections within the Cordilleran geosyncline, in order to determine the fitness of endothyroid foraminifera n correlating Mississippian deposits of North merica. The Cordilleran region is marked y a very complex structure, with faults and tratigraphic and angular unconformities. A ithologic correlation is ruled out, under such onditions, and the paleontologic method alone an give a true picture of the Cordilleran eologic history in the Mississippian.

The author has found well preserved endothyroid foraminifera, in adequate amounts, in most sections along the Cordillera, from Montana to Arizona. He identified Mississippian deposits there, carrying a fauna typical f contemporaneous deposits from the Mississippi valley (Central States). Foraminifera vere lacking only in the very lowest Mississippian rocks resting on barren rocks assigned o the Upper Devonian. Mississippian deposits are overlain by the Pennsylvanian.

Certain groups of endothyroid foraminifera, with a wide lateral and a comparatively narrow vertical distribution, made it possible o identify the following four microfaunal zones in the Cordilleran Mississippian:

1) Granuliferella; 2) Plectogyra tumula; 3) Endothyra spiroides; and 4) Endothyra symmetrica. The overlying deposits are assigned by E. Zeller to the Paramillerella zone, with certain reservations, because representatives of Paramillerella occur in the uppermost Mississippian beds and stray into the basal Pennsylvanian.

E. Zeller correlates the Granuliferella zone with the Kinderhood of the standard section of the U.S.; the Plectogyra tumula zone, with the Osagean. The Endothyra spiroides and Endothyra symmetrica zones are correlative with the Meramecian (Salem, St. Genevieva, St. Louis limestones).

Zeller notes two foraminiferal assemblages, in overlying deposits correlative with the Chester formation. One of them (in Arizona) is analogous with the assemblage of Visean foraminifera from the Central States Chesteran; the other exhibits great similarity to the upper Visean foraminiferal assemblages from Europe and North Africa. Deposits with the European type assemblage of upper Visean foraminifera were found in Utah.

Zeller notes that endothyroid foraminifera deserve the closest attention inasmuch as they open a new era in the history of foraminifera. They appear in Lower Mississippian beds in such abundance that locally they may be called rock-making. Such a mass appearance of endothyroids is explained by E. Zeller by the possibility of their being the first foraminifera to build their test of calcium carbonate.

With regard to the wall structure in some forms with a granular microtexture E. Zeller believes that this granulation may have been primary. In his opinion, the presence of minute calcium carbonate grains in the shell wall is a result of their chemical secretion by the protoplasm, rather than of their agglutination from the surrounding medium.

In support of his thesis, Zeller refers to some representatives of genera Plectogyra and Endothyra which secrete calcium carbonate from the protoplasm, in secondary deposits within the test. He believes that these organisms could build their shell in the same way, by chemical precipitation of calcium carbonate from the protoplasm. He notes, however, that the granulation is often determined by the degree of preservation of a shell and that the question of its primary or secondary nature must remain open, for the time being.

We should like to offer some comment on the systematic part of E. Zeller's paper. One cannot agree with assigning to the same species Plectogyra tumula, a form displaying a regular evolute coiling of whorls and a discoidal test (Table 79, Figs. 7, 8, 9, 23), and

forms with an involute coiling (Plate 77, Fig. 11; Plate 82, Fig. 16). A common feature of these forms is the presence of high massive secondary secretions while they differ considerably from each other in other features. It is well known that secondary secretions have been observed in many species belonging not only to different genera but to different families. Unquestionably, Plectogyra tumula includes representatives not only of different species but of different genera. Thus P. tumula (Table 77, Fig. 11) is very much like Chernyshinella tuberculata Lip. and probably belongs to that genus. P. tumula (Plate 79, Figs. 7-9, 23) is close to representatives of Tournayella and differs from its species known from the Soviet Union by a more distinct segmentation of the tubular chamber and by massive secondary secretions. Most likely, these forms should be assigned to a new genus of the Tournayellidae family.

We also believe that Granuliferella granulosa has assigned to it forms differing from each other in the form of their test, the nature of coiling, and the wall structure. For instance, Gr. granulosa (Plate 77, Figs. 1, 19) differs from Gr. granulosa (Plate 79, Figs. 20, 21) by its thicker and coarse-grained wall. Gr. granulosa (Plate 81, Figs. 4, 5, 10, and especially 12) is close to the Chernyshinella glomiformis Lip. group, etc.

In Soviet usage, the correlating value of foraminifera is not in the leading zonal species but in a general faunal assemblage. E. Zeller, like other American micropaleontologists, uses zonal (index) forms in stratigraphic subdivision and correlation. The vertical distribution of index species may change within short distances, for many reasons, thus leading to errors in designating zonal stratigraphic units. The author does not list other small foraminifera accompanyin the endothyroids. It is not clear whether suc an omission is due to the lack of these foraminifera or to their inadequate study. It should be added that works of Soviet micropaleontologists — O.A. Lipina, L.P. Grozdilova, N.S. Lebedeva, and others — on Tournaisian foraminifera (corresponding to the Lower Mississippian of the Cordilleras) appear to be unknown to E. Zeller. Familiarity with Soviet monographs on systematics and the stratigraphic distribution of lower Carboniferous foraminifera, described from various parts of the Soviet Union, could have provided E. Zeller with a better understandin of typical features of his foraminiferal assemblage.

On the whole, his paper is interesting and worthy of the attention of those micropaleontologists studying lower Carboniferous foraminifera.

His data on the distribution of endothyroid foraminifera in the Mississippian of the Cordillera lead to certain conclusions on the correlation of lower Carboniferous sections from the Soviet Union and the U.S.

As shown in the systematic part of his paper, endothyroid foraminifera are represented by

Correlation Table for lower Carboniferous of the U.S.S.R. and U.S., by Endothyroid foraminifera

| Stage | Russian Platform | Urals | Siberia | Cordillera | Standard Section, U.S. | |
|---|---|---|---|---|---|---|
| Visean | Deposits with typical Visean foramiferal assemblage | | | Zone Paramillerella | Chesteran | Mississippian |
| | Erosional break | | | Zone Endothyra symmetrica | Meramecian | |
| | | Eostaffella nalivkini | Endothyra transita | Zone Endothyra spiroides | | |
| Tournasian | Plectogyra tuberculata | Plectogyra tuberculata | Plectogyra tuberculata | Zone Plectogyra tumula | Osagean | |
| | Chernishinella glomiformis | Chernishinella glomiformis | Chernishinella glomiformis | Zone Granuliferella | Kinderhook | |
| | | Etrennian | | ? | | |

Upper Devonian

numerous and diversified forms, in the Mississippian of the Cordillera.

There is great and conspicuous similarity in principal morphologic features for most Plectogyra and Endothyra species, in the Mississippian of western North America and for some representatives of Plectogyra and Endothyra (Eostafella Rauser) described from Tournaisian and Visean deposits of the Urals, Siberia, and the Russian platform.

A comparison of the endothyroid foraminiferal assemblages alone leads to the conclusion that lower Carboniferous assemblages from the Cordilleran geosyncline are close to those from Siberia. The Uralian lower Carboniferous foraminiferal assemblage is closer to that from the European zoogeographical province. This also is confirmed by assemblages of brachiopods and corals, which made it possible to identify in the Urals and Russian platform, stratigraphic units corresponding to the Tournaisian and Visean of Western Europe.

Especially interesting are the Endothyra spiroides and the Endothyra symmetrica zones which may be correlative with the European zoogeographic province beds (the Productus sublaevis zone) transitional from Tournaisian to Visean. As in Europe, the appearance of some Endothyra (Eostafella Rauser) representatives may be regarded as the Tournaisian-Visean boundary. This is not contradicted by data of E. Zeller who assigns the Endothyra spiroides and the E. symmetrica zones to the Meramec formation correlated in the U.S. with the Visean of Western Europe.

According to Zeller, upper beds of the Endothyra symmetrica zone may correspond to the Chester formation represented by higher Visean horizons.

The similarity in morphologic features and the general character of evolution of the entire endothyroid fauna and its individual representatives allows a more certain correlation of lower Carboniferous sections from these two distant provinces.

This correlation of lower Carboniferous deposits from the Soviet Union with their equivalent in the U.S. undoubtedly is very general. We believe, however, it may constitute a basis for the further and more precise correlation of stratigraphic subdivisions from these two countries.

## THE PAPER OF B.M. SHTEMPEL', "AGE OF CONGLOMERATES FROM THE MIDDLE KAMCHATKA RANGE METAMORPHIC SEQUENCE"[4]

by

Yu. V. Makarov

Doklady of the Academy of Sciences, U.S.S.R., t. 114, no. 5, 1957 carries a paper of B.M. Shtempel', Age of Conglomerate from the Middle Kamchatka Range Metamorphic Sequence. From his faunal findings, the author assigns to the Paleogene the conglomerate and all of the Kamchatka metamorphics. In so doing, he refers to our study in that area. The results of the final analysis of the 1956 field data condemn B.M. Shtempel's conclusions on the age of the Middle Kamchatka Range metamorphics.

The finding itself of lower Tertiary rocks in the Middle Kamchatka Range undoubtedly is of major signficance; the identification with them of the Kamchatka metamorphics is without any justification. As correctly stated by B.M. Shtempel', the conglomerate rests with an angular unconformity on phyllite of the so-called Malkin sequence, known to be Paleozoic. The phyllite changes gradually to crystalline schist and gneiss, which is also correctly noted by him. This very relationship between the phyllite and gneiss precludes any possibility of conglomerate occurring between the two. Paleocene conglomerates undoubtedly are stratigraphically higher than the Kamchatka metamorphics: gneiss, crystalline schist, and phyllite. This is convincingly demonstrated by the following facts:

1) the conglomerate carries pebbles not only of phyllite but also of gneiss, crystalline schist, and of granite which cut them (and do not cut the conglomerate);

2) a stronger deformation of metamorphic rocks as compared with the conglomerate, and their undoubtedly more intensive regional metamorphism.

The visible position of conglomerate between phyllite and gneiss, along with its lower topographic position in the area south of Icha River, is explained by a normal fault which limits the conglomerate unit in the east, bringing it in contact with the gneiss. This fault has been traced along almost its entire length, from zones of mylonitized and cataclastic rocks, and is well substantiated by

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[4] Po povodu stat'i B.M. Shtempel' "Vozrast konglomeratov metamorficheskoy tolshchi sredinnogo khrebta Kamchatki."

the accompanying linear meridionally oriented andesite dikes.

Militating against the occurrence of conglomerate between phyllite and gneiss are their local "islands" resting directly on the gneiss. This circumstance made it possible to determine, more or less definitely, the amount of throw, tentatively estimated at 150 to 200 meters.

A standard lower Tertiary section carrying at its base the conglomerate described by B.M. Shtempel' has been observed north of Oblukovino settlement, in the Baraba Mountain area. Resting quite conformably on conglomerate, here, is a fairly thick sequence of sedimentary and extrusive pyroclastic rocks, formerly assigned to the Upper Cretaceous. The Paleogene age of the conglomerate makes it possible to tentatively assign these mostly barren extrusives to the Paleogene. This assumption is confirmed also by paleophytologic analyses of specimens from the so-called Kirganin formation, formerly supposed to be Upper Cretaceous. These analyses have revealed the presence of Paleogene spores and pollen.

It follows from the foregoing that the finding of a flora in the Middle Kamchatka Range conglomerate pinpoints the age of extrusive pyroclastic bodies of that range, formerly assigned to the Upper Cretaceous. This, in turn, refutes the opinion of most far-eastern geologists that Tertiary deposits in the central part of the Middle Kamchatka Range are represented solely by the Neogene. Further study undoubtedly will turn up in the Middle Range equivalents of the Paleogene from the east and west Kamchatka coasts where the Paleogene is best developed, being represented by sedimentary rocks with a fossil flora and fauna.

Thus, the very question of "the age of conglomerate from the Middle Kamchatka Range metamorphics" is stated incorrectly. These conglomerates are basal in a thick sequence of sedimentary and extrusive Paleogene rocks and have nothing in common with Paleozoic metamorphics of the Middle Range.

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# CHRONICLE

## AWARDING OF THE 1959 LENIN PRIZES IN GEOLOGY TO SCIENTIFIC WORKERS OF THE ACADEMY OF SCIENCES, U.S.S.R.[1]

The recipients of the Lenin Prizes for 1959 were the following: in the Division of Science, Corresponding Member of the Academy of Sciences, U.S.S.R., and President of the Academy of Sciences of the Uzbek S.S.R., Khabib Mukhamedovich Abdullayev, for his work on the role of granitoids in post-magmatic mineralization; in the Technical Division, Senior Scientist of the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Academy of Sciences, U.S.S.R., Candidate in Geologic and Mineralogic Sciences Michail Ivanovich Kalganov, for his discovery and exploration of the rich iron deposits in the Belgorod area, the Kursk Magnetic Anomaly, in collaboration with a group of geologists from the Ministry of Geology and Mineral Conservation (A.A. Dubyanskiy, M.N. Dobrokhotov, I.A. Rusinovich, N.G. Schmidt, S.I. Chaykin, and M.I. Yakovlev).

The awarding of the Lenin Prizes for these efforts is an indisputable proof of the achievements of our science in the field of ore deposits, petrography, and metallogeny — in that field of geologic knowledge which is most important in the economy of the country, in the successful fulfillment of tasks set up by the Party and the Government for the Seven Year Plan of development of the people's economy in the U.S.S.R., and in the satisfaction of material needs of the Soviet man.

The development of scientific concepts on ore formation, in Kh.M. Abdullayev's work, on one hand, and the practical results of theoretical research, achieved by M.I. Kalganov, on the other, demonstrate the close union of science and its practical application, in our country.

[1] O prisuzhdenii Leninskikh premiy 1959 g. po geologii Rabotnikam Akademii Nauk SSSR.

Of the works of Kh.M. Abdullayev on the formation of ores and on igneous activity, the following may be singled out:

1. Genetic Relations of Mineralization to Granitoid Intrusions; first edition, 1950; second edition, 1954;

2. Dikes and Mineralization; published in 1957;

3. Igneous Activity and Related Metallogeni[c] Processes; published in 1958;

4. Main Features of Igneous Activity and Metallogeny in the Chatkal-Kuramin Mountains[,] published in 1958.

These works have attracted the attention o[f] the geologic fraternity by their timely formulation of basic problems of the relation between igneous activity, particularly of granitoid intrusions, and ore deposits, a very essential contribution both academically and practically.

In 1951, the first edition of the Genetic Relation of Mineralization and Granitoid Intrusions was a subject of lively discussion in the former institute of Geologic Sciences, Academ[y] of Sciences, U.S.S.R. (see Izvestiya Akademi[i] Nauk SSSR, ser. Geol., no. 4, 1951); in 1954, the second edition of this book was reviewed in considerable detail, in this journal (no. 3, 1954); the Dikes and Mineralization also was given a special review, in this journal (no. 5[,] 1958). The publication of these works of Kh. M. Abdullayev was noted in other periodicals, as well.

Critically examining the voluminous publis[hed] material on the relation of igneous activity a[nd] mineralization, as well as his own field data [on] Central Asian deposits, Kh.M. Abdullayev ha[s] determined that a superposition of several igneous cycles within individual zones leads t[o] a complex multistage development of magmati[c] and metallogenic processes.

The features of development of igneous activity have demonstrated the hypabyssal

ıture of Central Asian granitoids, with ısimilation processes playing an important ɔle in the exclusive development there of :arn ore deposits. The author emphasized e post-magmatic nature of Central Asian ɛposits.

An important achievement of Kh.M. Abdul-yev in considering the role of granitoids in e process of mineralization, is his advance-ent and formulation of the importance of e geologic medium in petrogenesis and the igin of endogenic ores.

The work of Kh.M. Abdullayev on granit-ds and on the relation between mineraliza-on and igneous activity is well known to oviet geologists, as well as abroad.

M.I. Kalganov has been studying the geol-y of rich iron ores in the Kursk Anomaly ısin, since 1949. In cooperation with pro-ıction geologists, he took an active part in e discovery and study of rich iron ores in e Belgorod district, the Kursk Magnetic nomaly.

The group, commended in the 1959 Lenin ize citation, has discovered and studied ajor deposits of high grade iron ores with t a slight silica content (3.5% to 5.5%) and small amount of noxious impurities (sulfur ıd phosphorous). The high grade of these es will bring about a lower production cost cast iron and steel, as compared with her iron-producing areas.

The work of recent years has discovered nmense reserves of rich iron ores in the ursk Magnetic Anomaly. The volume of rruginous quartzite representing lean ores ith an average iron content of 35% to 37% practically inexhaustible.

## CIENTIFIC SESSION OF THE COMMISSION ON STUDY OF REGULAR PATTERNS IN THE DISTRIBUTION OF ENDOGENIC ORE DEPOSITS[2]

On May 18-19, 1959, a session of the ommission on the Study of Regular Patterns ı the Distribution of Endogenic Ore deposits as held at the Institute of Geology of Ore eposits, Petrography, Mineralogy, and Geo-ıemistry (IGEM), Academy of Sciences, .S.S.R. Participating were representatives f the Moscow, Leningrad, and other scien-fic research and industrial geologic organi-ations (Northeast U.S.S.R., Urals, Siberia, Kazakhstan, Central Asia, Caucasus, Ukraine).

In his introductory address, Chairman Professor G.A. Sokolov (IGEM, Akademiya Nauk SSSR) informed the participants on the basic fields of work, the problems, and the working schedule of the Commission for 1959 and 1960. One of the main projects is an extensive metallogenic study and the making of detailed exploration maps for the most effective direction of prospecting work. In connection with that, the first session of the Commission was dedicated chiefly to the metallogeny of ore regions.

Metallogenic features of the Kara-Tau were taken up in detail by Professor Ye.Ye. Zak-harov (MGRI), on the basis of an exploration map. Lead-zinc deposits of that province, associated with Hercinian granitoid intrusions, are supposed to be epigenetic with relation to the enclosing carbonate rocks (chiefly dolo-mite), Famennian to Lower Tournaisian in age. For that reason, the structure is the ore controlling factor. Here, the lead-zinc deposits are located in the hanging wall of the main Kara-Tau deep-seated fault, being directly associated with tectonic zones con-necting the block structures. The formation of these zones is connected with the fault movement.

Ye.A. Radkevich and I.N. Tomson (IGEM, Akademiya Nauk SSSR), in their paper Types of Ore Areas of the South Maritime Region, designated metallogenic zones and ore areas, on the basis of a tectonic differentiation of that region which is marked by a variety of sedimentary, volcanic, and intrusive forma-tions and ore bodies. It has been established that longitudinal tectonic elements determine the distribution of metallogenic zones and subzones, while transverse structures affect the type of mineralization and control the distribution of ore areas (gold, cassiterite-quartz, cassiterite-sulfide, and other deposits).

The paper of Professor V.N. Kozerenko (All-Union Extension Polytechnic Inst.) on The Significance of Structural Facies Zones in Metallogenic Study, as Illustrated by Eastern Trans-Baykalia gives a detailed description of structural facies and associated metallogenic zones for the two main stages in the development of Eastern Trans-Baykalia: the Upper Paleozoic and the Mesozoic. It has been recognized in the study of metal-logenic provinces (Eastern Trans-Baykalia, Western Tyan'-Shan') that the position of such large and long-developed structural elements as the structural facies zones deter-mines the main regular patterns in the distribution of different types of ore depos-its, and primarily their zonal distribution, very clearly demonstrated in Eastern Trans-Baykalia.

[2]Nauchnaya sessiya komissii po izucheniyu akonomernostey razmeshcheniya endogennykh ıestorozhdeniy.

In his paper, Main Types of Ore Regions in the Rudnyy Altay, G.F. Yakovlev (Moscow State University) briefly described the three main types of ore areas of that polymetal belt, essentially related to its main tectonic units: zones of fracturing, anticlinoria, and synclinoria. The entire history of geologic development has determined not only the structure of these zones but the metallogenic features of their ore areas. The practical significance of ore areas is different for different types; most interesting are ore areas in shattered zones and in anticlinoria (the block-fold type), with the latter being more common. The block-fold types of ore areas, marked by an association of polymetal deposits with junctions of block folds where persistent edge faults are developed, appear to have a more than merely local significance (Gornyy Altay, Kara-Tau).

The paper of Ye.A. Radkevich (IGEM, Akademiya Nauk, SSSR) The Principles of Differentiation of Ore Provinces is of interest as an attempt at classifying ore regions by their types. Ore provinces are divided into the following classes and sub-classes:

I. The platform ore provinces, with two sub-classes, according to the nature of their mineralization: 1) in the crystalline basement; and 2) in the platform mantle, as well as along later faults cutting the crystalline shields.

II. Ore provinces of geosynclines, with two geochemically different sub-classes: 1) femic, with basic and ultrabasic rocks; and 2) sial, with granite.

III. Ore provinces of rejuvenated platforms and ancient fold regions. Designated as a special type of superimposed structural zones are young volcanic belts similar to the Pacific

A detailed description of metallogeny for ore regions in all of the above-named groups of ore provinces was given in detailed tables which illustrated the paper.

Thus all papers emphasized the fact that types of ore belts and areas depend not only on the history of geologic development of a given province but — and what is more important — they are closely connected with their spatial position, i.e., with their association with one or another tectonic zone. The direction of development of these zones is determined by the type of a platform of a geosyncline, reflected in the nature of sedimentary and volcanic formations, intrusive bodies, and geologic structures, and affecting the distribution of ore deposits. The determination of regular patterns in the distribution of various types of ore regions is an important element in compiling exploration metallogenic maps which chart the direction of prospecting.

The reading of papers was followed by lively discussion where approval was voiced for their content and its treatment. The criticism was confined mostly to the absence of regional exploration maps and to the lack of specific recommendations as to the method of compilation of such maps.

In his concluding address, Professor G.A. Sokolov summed up the results of work of this scientific session which has successfully completed the basic task set before it.